FABRIC FORMWORK

Investigations into Formwork Tectonics and Stereogeneity in Architectural Constructions

Manelius

Fabric Formwork

Anne-Mette Manelius
PhD Dissertation, 2012

The Royal Danish Academy of Fine Arts
Schools of Architecture, Design, and Conservation
School of Architecture
Institute of Architectural Technology
Center for Industrialized Architecture

FABRIC FORMWORK FOR CONCRETE

INVESTIGATIONS INTO FORMWORK TECTONICS AND STEREOGENEITY IN ARCHITECTURAL CONSTRUCTIONS

PhD dissertation by Anne-Mette Manelius

"Fabric Formwork for Concrete - Investigations into Formwork Tectonics and Stereogeneity in Architectural Constructions"

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CONTENT

1/ BEGINNING	10	Summary (English and Danish)
	12	Selected terminology
	14	Organization of the dissertation
	15	Background
2/ THEORY AND CONCEPTS	21	Introduction and research question
	29	Methodology
	43	Conceptual framework
3/ PRACTICAL INVESTIGATION	59	Concrete and concreting
	69	Stereogeneous construction
	75	Textiles in construction
	79	Fabric formwork for concrete
4/ ANALYTICAL INVESTIGATION	99	Documentation and comparison
	105	Presentation of analytical cases
	107	Frame
	145	Form Tie
	173	Textile
5/ PERSPECTIVES	225	Perspectives of findings
		Reflection of methodology and findings
		Contribution to practice
	233	Bibliography and references
APPENDIX/ EXPERIMENTAL DATA	241	1/ CAST Columns at RDAFASA
		2/ Tek 1 2009
		3/ Ambiguous Chair
		4/ Vermont Wall
		5/ Concrete Flesh, Chalmers
		6/ Tek1 2010
		7/ Concretum, Erasmus Summer School
		8/ Tek1 2011
		9/ Texts

1/ BEGINNING

Summary and Sammendrag (Danish)
Selected terminology
Organization of the dissertation
Background

SUMMARY

Fabric Formwork for Concrete - Investigations into Formwork Tectonics and Stereogeneity in Architectural Constructions

This doctoral dissertation is the result of an Industrial PhD project about fabric formwork, a new construction method, for which the high tensile strength of flat sheets of fabric is used to support fresh concrete.

Coupling existing material technologies of concrete and textile will contribute to meet unseen architectural potentials for concrete. This practical hypothesis is investigated through the overall question: *what are the architectural potentials of fabric formwork for concrete in regard to the materials, the principles, and the architectural expression of construction?*

The research question and a series of sub questions are investigated as research through design inspired by experimental research in the field of fabric formwork and framed in the Danish Industrial PhD Programme between to industrial partners, the contractor E. Pihl & Son and the architectural office schmidt hammer lassen architects.

In general the dissertation contributes to the development of the field of research through design as well as practical and theoretical studies of tectonic practice, the architectural expression of constructional materials and techniques. More significantly the dissertation contributes in two ways to the knowledge and practice of fabric forming as well as the implementation of the construction method in contemporary construction. First, through the making, documentation, and comparative study of a large amount of empirical data, and secondly, by the study of the roles of specific details and principles of its making and their consequence on concrete form, surface, and construction.

Fabric as well as concrete is a common description of a group of materials and their manufacturing procedures.

In their flexibility and fluidity, respectively, each of the material groups can be subject to manipulation. As the fluid, fresh concrete meets tensioned fabric during concreting, the two materials enter a dialogue in tension between relaxation and constraint. This dialogue, in which concrete is not merely suppressed by its mold, challenges the dichotomy of concrete as either fluid or solid.

In order to develop fabric formwork in theory as well as practice, the dissertation argues for an expansion of the concept of concrete as an architectural material as a series of conditions between fluid and solid. This concept of concrete as material *and* process is framed in the concept of *stereogeneity*, which is coined in the dissertation. The word is constructed by the two Greek words *stereos* (solid) and *ginomai* (to begin to be).

Textile as an architectural material is viewed as surface, structure, and metaphor respectively.

The dissertation's view on architectural technology is based on the Greek concept of *techné*, which allows a study of inherent artistic and practical aspects of technology.

The relationship between the fabric and its boundary condition in fabric formwork structures has a direct formal consequence on cast concrete. This entails that core formwork elements categorized as frame, form tie, and textile, have overlapping technical and symbolic roles before, during and after construction. The direct formal consequence of formwork construction on concrete cast in fabric molds thus offers practical and theoretical questions about the nature of fabric-formed concrete and the relation between the molded and the mold. This leads to a special attention in the dissertation of the relation between concrete and the principles, materials and methods of its making. Furthermore the concept of architectural technology frames the investigation of which textile principles and notions can be transferred to the construing and construction of concrete.

The dissertation is divided into *practical*, *empirical*, and *analytical* investigations.

The *practical* investigations are presented as a thematic selection of material notions and principles of making for textile and concrete construction. Formwork tectonics describes the relation construction principles, construction procedures, and their expressed physical manifestation.

The *empirical* investigations are developed through the author's experimental architectural practice and through the organization and teaching of student workshops. The results of the workshops count more than forty full-scale concrete objects. Sets of experimental data include the concrete objects and student reports consisting of the documentation of the process in selected drawings, reflective or descriptive writing as well as photos of procedures, details and objects.

The *analytical* investigations consist of the categorization, description and interpretation of experimental data. Seven selected analytical cases are presented and analyzed to discuss the multiple technological roles of a specific formwork element, frame, form tie, and textile, and its architectural potentials. Focus is placed on the architectural potentials that lie in the principles and materials of formwork construction and their stereogeneous consequence, the expressed relation between material and process.

The empirical work of the thesis work is summarized in the extended appendix *Experimental Data*. Covering eight workshop situations chronologically, the appendix includes the context, the assignments and the resulting student projects as well as reflections by the author. This collection of experimental data can work independent of the dissertation as inspiration for other teachers. Furthermore, the collection of construction principles can provide inspiration to practitioners within architecture and construction.

SAMMENDRAG

Tekstilforskalling til beton - undersøgelser af forskallingstektonik og stereogenitet i arkitektoniske konstruktioner

Afhandlingen er resultatet af et erhvervsPhDprojekt om tekstilforskalling, en ny støbemetode som udnytter tekstilers høje trækstyrke til konstruktion af beton.

Det er projektets praktiske hypotese, at koblingen af eksisterende materialeteknologier indenfor beton- og tekstilindustri vil bidrage til at indfri arkitektoniske potentialer for beton. Hypotesen undersøges gennem det overordnede forskningsspørgsmål hvad er de arkitektoniske potentialer for tekstilforskalling til beton i forhold til materialer, principper og arkitektonisk udtryk?

Forskningsspørgsmålet og en mængde underspørgsmål undersøges med metoder for arkitektonisk eksperimenterende praksis (research through design) med inspiration fra eksperimenterende forsknings- og undervisningspraksis indenfor tekstilforskalling i Canada og Skotland. Metoden kobles til en anvendelsesorienteret kontekst i form af erhvervsPhD-projektets forankring mellem entreprenørvirksomheden E. Pihl & Søn og arkitektvirksomheden schmidt hammer lassen architects.

Afhandlingen bidrager generelt til udviklingen af forskningsmetoder gennem arkitektonisk udviklingsarbejde, samt teoridannelse indenfor tektonisk praksis - studier af arkitektonisk udtryk baseret på konstruktionsmetoder og –materialer. Specifikt bidrager afhandlingen med ny viden, praksis og grundlæggende teoridannelse indenfor tekstilforskalling til beton, samt i forhold til implementering af tekstilforskalling i en moderne bygbar kontekst. Først i form af tilvirkning, dokumentation, kategorisering og komparativt studie af en stor mængde empiri. Dernæst, i form af analyser og teoridannelse baseret på særlige detaljer og konstruktionsprincipper og deres arkitektoniske konsekvens på betons form, overflade og konstruktion.

Både tekstil og beton er en fællesbetegnelse for en gruppe råmaterialer og deres fabrikation. Materialegrupperne rummer i deres fleksibilitet hver især en slags tilpasningsegenskab og i mødet mellem frisk beton og udspændt tekstil udspilles en dialog imellem dem, mellem træk og tryk. Denne dialog, hvor beton ikke underlægger sig sin støbeform, påvirker forståelsen af beton som enten flydende eller fast.

For at kunne udvikle og udnytte fleksibel forskalling i teori og praksis, argumenterer afhandlingen for en udvidet forståelse af beton som et arkitektonisk materiale i form af en række tilstande mellem flydende og fast. Denne materialeforståelse af beton som både materiale *og* proces udvikles i begrebet *stereogenitet*, som introduceres i afhandlingen, baseret på de græske ord *stereos* (solid, fast) og *ginomai* (at begynde at være).

Tekstil som et arkitektonisk materiale forstås som flade, konstruktion og metafor.

Afhandlingens arkitektoniske teknologiforståelse er baseret på det græske begreb *techné*, hvilket tillader overlappende undersøgelser af kunstneriske og praktiske aspekter af arkitekturens teknologi.

Forskallingens opbygning af henholdsvis ramme, formbinder og tekstil får en direkte og let aflæselig formel konsekvens på støbt beton. Forskallingselementernes udformning kan således kategoriseres som knudepunkter, der rummer både tekniske og symbolske roller før, under og efter konstruktionen af beton.

Dette rejser praktiske og teoretiske spørgsmål om den tekstilforskallede betons natur, samt om relationen mellem det støbte, støbeform og støbning, og afhandlingen bidrager derfor til den arkitektoniske ordforråd og praktiske udformning af sammenhængen mellem betonkonstruktioner og de principper, materialer og teknikker de er resultatet af.

Den arkitektoniske teknologiforståelse danner også rammen undersøgelsen af *hvilke tekstile principper og begreber kan overføres til udformning og konstruktion af beton*.

Afhandlingen er inddelt i *praktiske*, *empiriske* og *analytiske* undersøgelser.

De *praktiske* undersøgelser er udvalgt tematisk til at undersøge anvendelsen af beton og tekstil i arkitektoniske konstruktioner. Begrebet forskallingstektonik, eller på dansk formværk, udfoldes her og beskriver relationen mellem konstruktive principper, processer og materialer, og deres fysiske udtrykte manifestation.

De *empiriske* undersøgelser af udviklet i forfatterens egen eksperimenterende arkitektoniske praksis og gennem planlægningen og undervisningen af en række workshops for studerende. Resultater af disse workshops er over fyrre betonobjekter i fuld skala. Eksperimentelle datasæt består dog, ud over betonobjekterne, af rapporter med dokumentation af ideer og proces i udvalgte skitser, reflekterende og beskrivende tekst, samt fotos af proces og resultater.

Analytiske undersøgelser af den empiriske data indledes med en kategorisering og beskrivelse af de eksperimentelle datasæt. Herefter studeres syv udvalgte analysecases ud fra de flertydige teknologiske roller over tid, af forskallingselementerne ramme, formbinder og tekstil. Fokus er på arkitektoniske potentialer for de strukturelle principper, konstruktion og stereogeniske konsekvens, den udtrykte relation mellem materiale og proces.

Projektets empiriske materiale er opsummeret i en udvidet bilagssamling med baggrund, opgavebeskrivelser og uddrag af de studerendes besvarelser, samt forfatterens kommunikation og refleksioner over det workshopbaserede undervisningsforløb, samt egne eksperimenter i otte eksperimentelle sammenhænge. Denne samling eksperimentel data kan fungere uafhængigt af afhandlingen som inspiration til andre undervisere, forskere, samt praktikere indenfor arkitektur og byggeri.

TERMINOLOGY

Selection of key terms and concepts

Concrete and cement

The term concrete is derived Lat. *concrēscere*, to grow together. The word cement is based on the ancient Roman definition of *caementum*, a mortar with a binding material for constructing walls. Béton is the term for modern concrete used in French, German and Danish. The word is derived from the Old French *betum* for a mass of rubbish.[1] See stereogeneity and condition.

Concreting

The procedures of pouring fresh concrete into a mold, or applying thin layers of fresh concrete on a surface.

Condition

According to the Retrospective Object Theory posed by the Danish artist and Professor Willy Ørskov an art object and its becoming can be understood over time as a series of conditions over time.[2]

Fabric

A planar textile structure produced by interlacing yarns, fibers, or filaments. The word fabric is derived from Lat. *fabrica*, workshop, and the French *fabriquer*, to manufacture, and describes a number of fabrications. The sense in English evolved via 'manufactured material' to 'textile.'

Formwork tectonics

The relation and careful joining of between parts and whole of formwork structures. The formwork tectonics of fabric formwork has the core parts: frame, form tie, and textile. Structural formwork principles, see *structure*.

Stereogeneity

Word derived from the roots of Gr. *stereos* (solid) and *ginomai* (to begin to be); describes concrete as a material *and* a process and is a coinage of the author. The formal definition is suggested as: '*the expressed manifestation into solid material form of a series of conditions from the construing and construction of structural formwork principles and concreting.*' See *condition*.

Structure and structural principles

The use of the word is influenced by the use in Danish *struktur*, from Lat. *struere* to pile up. The word covers the linkages and relationships that exist between parts of a whole.[3] The German architect Mies van der Rohe (1886 – 1969) defined structure in architecture as a philosophical concept: 'The whole, from top to bottom, to the last detail, with the same ideas.'[4] He saw structural order as a condition where 'form becomes a consequence of structure and not the reason for the construction.'[5] Structural formwork principles, see *formwork tectonics*.

Technology and techne

The word is understood through the Greek words *techne* 'art, skill, craft, method, system.' combining; and the root of *legein* 'to speak'. The architectural scholar Marco Frascari refers to a dual-faced notion of technology because it unifies the tangible and the intangible of architecture. Rhetorical, symbolic and reflective representations of technology thus refer to the *techne of logos*; scientific, instrumental and practical representations of technology refer to the *logos of techne*.[6]

Tectonics

Introduced to architectural discourse in the 19th century, several uses of the word are present in the dissertation: for practical use of tectonic thinking, see *structure* and *formwork tectonics*. Analytical use of tectonics as the expressed manifestation of initial structural principles and the materials and processes,[7] see *stereogeneity*.

Textile

The term originally describes a specific mode of fabrication, to weave; from Latin: *textilis*, woven, fabric, cloth. The word refers more generally to modes of construction for textiles. In the dissertation textile is used as a fabric surface, as structure as well as metaphor.

1 Peter Collins, *Concrete, the Vision of a New Architecture: A Study of Auguste Perret and his Precursors*, 2nd ed. (McGill-Queen's University Press, 2004), 21.

2 See Theory and Concepts

3 "Struktur", *Den Store Danske* (online dictionary, Denmark: Gyldendal, 2012), www.denstoredanske.dk, (Accessed 15-01-2012).

4 Ludwig Mies van der Rohe and Peter Carter, *Mies van der Rohe at Work*, reprint (org 1974). (London: Phaidon, 1999), 9.

5 Ibid.

6 Marco Frascari, *Monsters of Architecture* (Rowman & Littlefield Publishers, 1991), 116–17.

7 Sekler, Eduard, "Structure, Construction, Tectonics," in *Structure in Art and Science*, ed. Gyorgy Kepes (George Braziller, 1965), 89-95.

ORGANIZATION OF THE DISSERTATION

The dissertation is divided into five main parts and an appendix. Each main part contains several chapters gathered around a common theme: beginning, theory and concepts, practical investigation, analytical investigation, and perspectives.

1/ BEGINNING contains a summary of the dissertation, a selected terminology as well as the background for the conducted research.

2/ THEORY AND CONCEPTS starts out with an *introduction* and the *research questions*, followed by the presentation of the *methodology* used in the dissertation work.

In order to discuss architectural potentials for fabric formwork it has been relevant to define parameters, which with which to conduct such an investigation. A *dual understanding of techné* indicating reflective and instrumental aspects of technology, and the concept of *tectonics* theoretically frames the thesis.

Conceptually textiles are understood as surface, structure, and metaphor Additional concepts of formwork tectonics and stereogeneity concern concrete and concreting as a series of conditions between liquid and solid.

These material concepts are introduced in *Theory and Concepts* but have been clarified through the making, the categorization and interpretation of experimental data.

3/ PRACTICAL INVESTIGATION contains a series of chapters that spans between an overall introduction to the material concrete in regard to principles of construing and construction, and the specific formwork-tectonic materials, elements, and construction principles of fabric formwork.

Concrete and Concreting is the largest part of this section and contains selected themes within the architectural field of concrete and concrete construction.

The concepts of formwork tectonics and stereogeneity are applied to selected architectural examples. Textile elements are emphasized and architectural examples illustrate ways of thinking in regard to the construing and construction of architectural concrete structures, forms, space, and surface and include aspects of formwork tectonics, that is to say the relation between materials, parts and the whole in formwork structures, the procedures and materials of construction.

The emphasized range of textile thinking in the chapter provides a broad field of reference for the potentials within the scope of research, ranging between the symbolic notions of textile concrete and the instrumental principles of fabric formwork.

Then follows additional usage of *Textiles in Construction* to supplement the textile examples for concrete.

Fabric Formwork is the pivotal formwork-tectonic topic of investigation in the empirical and analytical parts of the dissertation. The chapter contains a presentation of the characteristics, the development, and principles of construction as well as examples of practice within research and construction.

4/ ANALYTICAL INVESTIGATION is the largest section of the dissertation. First the initial categorization and *Comparative Analysis* of experimental data is introduced followed by detailed studies of the construing and construction of seven selected experiments.

Three groups of studies are then introduced and discussed in regard to a dominant formwork element, *Frame*, *Form Tie*, and *Textile*. Within these formwork-tectonic themes, each of the analytical cases is studied in regard to technological roles of the formwork element. Following each group of analytical studies is a chapter, where the findings are summarized and discussed in regard to their architectural potentials.

5/ PERSPECTIVES is the last part and contains a summary of the findings from the analytical studies followed by perspectives for the potentials and for the applied methodology in regard to the themes of investigation, materials, principles, and architectural expression of construction. The statement of contribution to practice concludes the dissertation.

BIBLIOGRAPHY AND REFERENCES are in the back of the dissertation. Websites and images used are referenced directly in the notes in the dissertation.

The printed APPENDIX contains a fold-out table as well as a catalogue in which the experimental data is extendedly summarized, mainly visually.

Here eight workshops and their experiments are presented along with excerpts from student reports and documentations by the author.

Also, the experimental data is accompanied with different categories of published or communicated articles, documentations and reflections in note-form. The extensive appendix can provide inspiration for teacher/organizers of workshops and conductors of workshop-based research.

The last section of the appendix contains selected texts. The enclosed cd contains all the student reports in Danish.

BACKGROUND

Starting point
Industrial PhD
Academic context
Theoretical context

STARTING POINT

Before embarking on the dissertation itself, this chapter offers a short introduction to the personal background and events leading to the work comprised in this thesis project.

An interest in the development of construction in architectural production has shaped my professional path, beginning with student jobs at the Danish Building Research Institute[1] (SBi), and the office of the Danish Building Clients' Association.[2] These two positions involved theoretical and practical aspects of what was then called the *new industrialization*[3] of architecture. A three-year employment at the Centre for Industrialised Architecture[4] (CINARK) in the Institute of Architectural Technology at the Royal Danish Academy of Fine Arts, School of Architecture (RDAFASA) brought a profound interest and knowledge of material technologies and 'concrete futures'. This work has led to the formulation and eventual launch of the PhD project on which this dissertation is the formal result.

The position at CINARK included the task of compiling a state-of-the-art review of architectural aspects related to the use of concrete in architecture. The outcome of this initial research task was published in Danish in September 2007 in a report titled *Flydende sten*[5], Danish for one of the nicknames of concrete: *Liquid stone*.

The fabric formwork technology emerged during my research for the state of the art report, Liquid Stone, as an intriguingly simple formwork principle in which woven fabrics were used as formwork –concrete was basically poured into a sock. Formal potentials for the material concrete and for processes of construction could be developed with the seemingly contradictory[6] relationship of two well-known groups of material technologies: textiles and concrete. Fabric formwork could be seen as low-tech and radical in its potential for producing sculptural concrete structures, for producing form-optimized concrete elements, and for using lightweight formwork for in situ concrete pours, all achievable with the use of flat textile sheets.

The publication of *Flydende sten* coincided with the conference and exhibition 'Creative Systems', organized by CINARK with the purpose of discussing how innovative technological or material systems can generate new ways of thinking and new approaches in architecture.[7]

The discussion and the insights into different research fields and on different scales of architectural research and production[8], as represented by the speakers, provided much inspiration for a group of Cinark-based PhD projects.[9]

Professor Mark West (born 1953), the director of CAST, the Centre for Architectural Structures and Technology, the University of Manitoba in Canada, was invited to speak as well as to contribute with the demonstration of fabric-formwork techniques as part of the exhibition. Three 3-meter high columns, constructed by Professor Mark West and his research assistant Aynslee Hurdal, were thus the first fabric-formed concrete prototypes at the RDAFASA.

Conference on Fabric Formwork

In May 2008, the world's first conference for fabric formwork[10] for concrete was held at the University of Manitoba in Winnipeg, Canada. Here I had the chance to encounter the state of art for research and methodology in this small, new research field, and I was able to find a starting point for initiating the industrial research project that officially began, in August 2008.

1 "About the Danish Building Research Institute (SBi)", October 2, 2006, www.en.sbi.dk (Accessed 15-12-2011) SBi is the Danish National Building Research Institute, which is now affiliated with Aalborg University. "SBi develops research-based knowledge to improve buildings and the built environment. SBi identifies subjects that are important for professionals and decision-makers involved with building and the built environment. And subsequently we communicate our knowledge to these groups"

2 "Danish Association of Construction Clients", n.d., www.bygherreforeningen.dk (Accessed 15-12-2011. Established in 1999 with the goal of influencing and improving the Danish construction sector.

3 Anne Beim, Kasper Sánchez Vibæk, and Thomas Ryborg Jørgensen, *Arkitektonisk Kvalitet & Industrielle Byggesystemer* (Copenhagen, Denmark: RDAFASA, Center of Industrialized Architecture, 2007), 25. The Danish *Nyindustrialisering* refers to a new wave of industrialization based on new IT-based tools that forms the basis for increased levels of customization, a new theme in the discussion of innovation in Danish construction around 2000 and thus is associated with the concept of 'Mass Customization'.

4 CINARK, "CINARK Profile", 2012, www.karch.dk/cinark_uk/ (Accessed 15-12-2011). Established in 2004. The Cinark's objective is described as follows: "Through increased research and teaching it is CINARK's aim to strengthen the school, the architectural education and the architectural profession when it comes to the use and understanding of the architectural potential in the industrialised building industry. The question at stake is how to develop the building industry towards advanced sustainable solutions. These efforts include a new organisation of the building industry; new processes of manufacturing as well as new design of building components. The centre strives to build up and communicate current knowledge in order to improve the dialogue between architects, manufacturers and users of sustainable industrial architecture."

5 Anne-Mette Manelius, *Cinark Overblik: Flydende Sten - Betons Arkitektoniske Potentialer. Et udredningsprojekt* (Copenhagen, Denmark: RDAFASA, Center of Industrialised Architecture, 2007).

6 Fiona McLachlan, "Form Follows Fabric," in *Fabric Formwork*, ed. Chandler, Alan and Remo Pedreschi (London, England: RIBA Publishing, 2007), 35. "*Casting concrete in fabric creates an inherent paradox. The relationship of materiality and form seems contradictory, in that something so inherently strong and utilitarian, with its associations of Minimalism and Brutalism, can be so flowing, soft and textured.*" McLachlan's description of fabric-formed concrete can be supplemented with additional textile associations.

7 Context: "Creative Systems" was a conference and exhibition organized and hosted by CINARK at RDAFASA in September 2007 about "systems" – both as methodologies, as in research, and as technologies, as used in practice.

Key note speakers were architect, Professor Mark West from the University of Manitoba in Canada: architect Stephen Kieran, partner and co-founder of Kieran Timberlake; architect, Professor Ludger Hovestadt ETH, Zürich/CAAD; and Matilda McQuaid, deputy curatorial director and head of the Textiles department at the Smithsonian's Cooper-Hewitt, National Design Museum, NYC, USA. The exhibition included four sections that introduced the work of the keynote speakers.

At this conference, a new organization was founded: the International Society of Fabric Forming (ISOFF);[11] the society website has become a source of information about researchers, contacts, events, and research papers from the growing community.[12]

INDUSTRIAL PHD

The PhD project is framed within the Danish Industrial PhD programme,[13] in which the scholar is an employee of a company as well as enrolled at an academic institution.

The project brief was developed at CINARK. The collaboration with two industrial partners instead of a strictly academic project was initiated based on the conviction that the applicability and availability of the fabric formwork method in a contemporary architectural practice is bound to the pragmatic procedures and production of concrete.

The project was originally intended as collaboration of three industrial partners: A concrete manufacturer, an architectural design office, and a concrete contractor. Eventually, two parts were formally involved as financial and professional actors in the project: the contractor E. Pihl & Son[14] and the architectural practice schmidt hammer lassen architects[15].

Communication

To enhance modes of communicating the project to colleagues in numerous locations, I launched the blog *Concretely*[16] as a platform for sharing developments in the thesis work, and within the field of innovation in concrete and architecture.

The blog has been updated periodically[17] throughout the past two years and has managed to generate awareness and some feedback. Feedback has come from colleagues with whom I might not otherwise have been able to initiate a dialogue, and the 'searchable blog existence' has also led to international exposure of the research.[18]

ACADEMIC CONTEXT

A new structure for architecture education that had been implemented in the RDAFASA Institute of Architectural Technology included a five-week course about materials and construction for first-year students, called TEK1.[19] The ambition for the course included a number of full-scale material workshops running for one week, during which students could become familiar with brick, wood, steel or concrete.

This specific 'hands-on' approach that is part of the academic understanding and didactics of the Institute has formed part of the basis for my gathering of empirical data

Workshops and colleagues

In the course of the past three years, I have organized and taught four concrete workshops with fellow researchers from the Institute of Architectural Technology.[20]

It has been fruitful and challenging to engage in teaching many students in these short and intense processes. Discussions about specific challenges with regard to teaching, structural

8 The ranges of production and viewpoints included analogue research methods into 'material systems' of textiles and concrete at CAST, highly digitized processes leading to manufacture through collaboration with the industry at CAAD, a survey of textile developments through new specialized techniques and materials curated at Cooper-Hewit, and the combined development-teaching-building-writing practice at Kieran-Timberlake.

9 Kasper Sánchez Vibæk, "System Structures in Architecture - Constituent Elements of a Contemporary industrialised Architecture" (PhD-Dissertation, RDAFASA, 2012). The dissertation applies theories and case studies provided by Kieran Timberlake. Johannes Rauff Greisen, "Architectonic Potentials in the use of Industrial Robots in Concrete Building Production" (Unpublished Industrial PhD dissertation, RDAFASA, Cinark, 2009). JRG's project applies theory and tools similar to work by Professor Hovestadt. The work comprised by Matilda McQuaid and especially Mark West have influenced the present dissertation.

10 "International Conference on Fabric Formwork 2008", May 2008, www.umanitoba.ca/faculties/architecture/cast/conference/index.html (Accessed 10-11-2011). The University of Manitoba, Faculty of Architecture and its Centre for Architectural Structures and Technology (CAST) hosted the first conference ever held on the subject of flexible fabric membranes as formwork for concrete structures and architecture on May 16-19, 2008 in Winnipeg, Canada.

11 "ISOFF - International Society of Fabric Forming", 2011, www.fabricforming.org/. (Accessed 20-11-2011). A provisional international board of directors was appointed, with Mark West, director of CAST, as ISOFF chair. The aim of this organization is to coordinate further connections between the conference participants and others around the world with an interest in advancing this new field. ISOFF is organizing the second international conference, which will be held in Europe in June 2012.

12 Ibid.

13 "The Industrial PhD Programme – Danish Agency for Science, Technology and Innovation", n.d., http://en.fi.dk/funding/funding-opportunities/industrial-phd-programme (Accessed 15-12-2011). An Industrial PhD project is a three-year PhD project with an industry focus, where the student is simultaneously employed by a company and enrolled in a university.

14 "E. Pihl & Son A.S.", n.d., www.pihl-as.com (Accessed 15-12-2011). Established in 1887. The company is among the largest Danish contractors and ranks number 116 among the world's larger contracting groups working on the international markets,

15 SHL Architects, "schmidt hammer lassen architects," Company Website, n.d., www.shl.dk/eng (Accessed 15-12-2011). Schmidt hammer lassen architects was established in Aarhus in 1986. The architects design mainly high-profile cultural buildings and more than 50 percent of the turnover comes from international projects. SHL has offices in Aarhus, Copenhagen, Oslo, London, and Shanghai.

16 Anne-Mette Manelius, "CONCRETELY," Blog, 2012, http://concretely.blogspot.com (Accessed 30-01-2012)

17 With over 60 posts since October 2009

principles, and architecture in general become very present and tangible when this dialogue is taken out of the office, possibly even out of the computer, and into the workshop environment where a specific architectural argumentation is developed through a creative process.

Several of the research projects at the Institute of Architectural Technology deal with material practice,[21] and with the implicit aim of any research in architectural construction of engaging in the built world, the material workshops organized by researchers of the institute have been fine occasions for engaging in conversations about the essentials of this culture and about methodologies of teaching and research.

See the table on the next page with indications of experiments and workshops as well as the number of participants, experiment conducted, and keywords.

THEORETICAL CONTEXT

Theoretically, the project attempts to continue the current discourse and methods in experimental tectonic practice, which can be found in the Institute of Architectural Technology at the RDAFASA.[22]

A focus on materiality and detailing that frames the particular cool daylight in Nordic building culture contains aspects of what has since been named tectonic thinking. The Nordic architectural scene still rests on the Functionalist tradition as represented by Danish architects such as Kay Fisker and Jørn Utzon, the Norwegian architect Sverre Fehn, the Swedish architect Sigurd Lewerentz, and the Finnish architect Alvar Aalto.

This focus upon the careful use of construction materials and articulated joints defines aspects of Nordic functionalist building culture that are cherished by several teaching studio departments at the RDAFASA.[23]

This practice of the tectonic concept suggests a holistic approach to construction technology, technique and materials with regard to function and spatial consequences. This practice as well as theories of tectonics is taught through studio-based teaching and through courses that include established concepts of tectonics.[24]

18 International sources, where the project or experiments have been featured: "Hormigón de encofrado textil. Tres experimentos en R.D.A.F.A.", no. 119, *Pasajes de Arquitectura y Crítica*. Dialnet (2011): 4 pp.; Christopher Stuart, ed., *DIY Furniture: A Step-by-Step Guide* (Laurence King Publishers, 2011), 4pp; Collectif, "Pour un amour de béton / Concrete Love", *L'Architecture d'Aujourd'Hui N 381* (Archipress, 2011), 163; Stacey Enesey Klemenc, "Decorative Concrete: Fabric Formwork" 10, no. 1, *Concrete Decor Magazine*, The Journal of Decorative Concrete (January 2010): 4 pp; Krokstrand, Ole H., Øyvind Steen Steen, and Magne Magler Wiggen. *Betongoverflater*. Gyldendal Norsk Forlag, 2011;

19 Named after the Institute of Architectural Technology. There are five course modules, named TEK1-TEK5.

20 Three TEK1 courses were organized with Architect and Industrial PhD student Johannes Rauff Greisen and engineer and Associate Professor Finn Bach. The Concretum, Erasmus Summers School 2010 was organized by Associate Professor Peter Sørensen.

21 PhD projects with material-specific foci include Mette Jerl Jensen, "Revitalisering af Teglmuren" (PhD-Dissertation / Industrial, RDAFASA, 2011).; and 'Architectonic Potentials in the use of Industrial Robots in Concrete Building Production' by Johannes Rauff Greisen; other projects investigate building processes that involve a variety of materials and techniques. Many researchers at the institute engage in institute courses, which often include the physical production of models or drawing.

22 RDAFASA, "RDAFASA Institute of Architectural Technology", 2012, www.karch.dk/uk (Accessed 15-12-2011). The Institute of Architectural Technology teaches and carries out research into the technical subject areas of architectural construction, including structural and perceptual subjects. The Institute develops, describes and disseminates information on the subject area with the intention of serving both as a source of inspiration and a necessary resource within the architectural profession. Subjects are addressed in combination and cross the range between technical-scientific and artistic-architectural subjects.

23 RDAFASA, "Departments and projects," Presentation of studio departments, *Karch*, 2012, www.karch.dk/uk (Accessed 15-12-2011). Departments are not explicit in their descriptions of methodologies on the website or in curriculums.

24 Including lectures, and courses on tectonics and material culture taught by Professor, PhD Anne Beim and Lecturer, PhD Thomas Bo Jensen, and Industrial PhDs Nini Leimand and Mette Jerl Jensen.

2/ THEORY AND CONCEPTS

INTRODUCTION AND RESEARCH QUESTIONS

METHODOLOGY

CONCEPTUAL FRAMEWORK

INTRODUCTION AND RESEARCH QUESTIONS

INTRODUCTION AND RESEARCH QUESTIONS

This dissertation is concerned with locating the architectural potentials of fabric formwork, a formwork technology in which sheets of textiles are used as a responsive formwork material for concrete molds in the context of construction.

Fabric formwork can be described by technical and formal characteristics:

- When a tensioned membrane is exposed to a uniform force, it deflects into catenary curves between points of restraint.
- The porosity of a woven membrane has a filter-effect under hydrostatic pressure. This improves the water-cement ratio of the concrete surface.
- The combination of selected formwork principles and materials, and the design of formwork elements have direct formal consequence for the concrete form and surface of the concrete structure.

The use of sheets of fabric to support fresh concrete has been investigated in patented construction systems since the turn of the twentieth century.[1] The development of a commercial field of formwork systems for geotechnical construction has especially developed since the rapid increase of cheap, technical textiles with the commercial implementation of plastics around 1950. A handful of artists and builders have worked on fabric-formed constructions principle since the 1980s and combined with architectural research in fabric formwork the past decades this has resulted in concrete typologies such as columns, walls, beams, shells, and sculptural objects and in the development of new principles of construction. Architectural potentials have mainly been discussed in regard to 'appropriate' construction and a specific intuitive practice of making. The practical application of fabric formwork in construction, however, has been limited to either sculpturally express the 'liquid origins' of concrete, or for the construction of walls for a few houses.

The present dissertation investigates the potentials for implementing fabric formwork in contemporary architectural constructions in an industrial context. The focus of the project is on aspects of architectural expression of constructional materials and techniques and the dissertation looks at the architectural potentials for fabric-formed concrete in regard to the components of its making. The aim to investigate architectural potentials for fabric-formed concrete is tied to the new. What are the unseen architectural possibilities for concrete?

The direct formal consequence of specific formwork principles offers a practical and theoretical focus on the relation between the concrete and the concrete mold and the project's main research question contains three themes in this regard:

What are the architectural potentials for fabric formwork for concrete structures with regard to the materials, the principles, and the architectural expression of construction?

The concept and practice of tectonics

The tectonic takes its name from Greek and relates to the craft of carpentry and the use of the axe; it has evolved to include the concept of the *tekton*, the carpenter. The meaning develops further from something specific and physical, such as carpentry, to encompass the notion of

Raw material	Pliable, tough resistant to tearing	Soft, 'plastic', easily formed, hardens	Stick-shaped, elastic, resistant to forces working along length	Strong, densely aggregated, resis-tant to compression
Procedure	Textile	Ceramics	Tectonics (carpentry)	Stereotomy (masonry, and so on)

Figure 1, A summary of Gottfried Semper's Classification of the Technical Arts into definitions of raw materials and their corresponding 'artistic activities' (procedure). Each division should be taken in its broadest sense. Gottfried Semper, *Style*, 109-110

making, involving the idea of *poesis*. The role of the *tekton* leads to the emergence of the master builder or *architekton,* which in turn evolves further into architecture to indicate a master of aesthetic rather than technological matters.[2]

The concept of tectonics was introduced in architectural discourse in the middle of the 19th century, at the onset of the Industrial revolution and surrounded by turbulent cultural and political change.[3] The writings by the German Architect and theorist, Gottfried Semper (1803-1879) face the challenge about the construction and style of architecture raised by the arrival new tools and techniques and thus requiring a new way of thinking and doing.

Semper is particularly relevant in the present study because his theories of textiles and textile procedures as architectural elements, as well as his theories on how to generate form through procedures, provide a significant seminal contribution for on which the present research rests. (Fig. 1)

The concept of *Bekleidung* (dressing) is perhaps the most widely used Semperian concept in Western architectural practice. Semper's theory of textiles is mostly linked to a theory of ornament and metaphor. The study of textiles in the present dissertation is based technical as well as symbolic role of textile surfaces in fabric formwork, mostly in that order. The complexity of discussing the architectural potentials of textiles used in concrete architecture is also illustrated by the fact that textiles are structures themselves.

Semper also leaves his mark on the methodology of this thesis in relation to the initial attempt at making a comparative analysis of the concrete elements as objects, isolated from their overall context. The taxonomy of instrumental significance – or structural-symbolic cores within the experimental data set of this thesis has led to the focus of the roles of specific formwork-tectonic elements.

The British architect, critic and historian Kenneth Frampton (born 1930) framed the reintroduction of the concept of tectonics to architectural theoretical discourse in his essay 'Rappel à l'Ordre -The Case for the Tectonic'.[4] Here he summarizes the development of the concept of the tectonic:

"From its conscious emergence in the middle of the nineteenth century with the writings of Karl Bötticher and Gottfried Semper, the term not only indicates a structural and material probity but also a poetics of construction, as this may be practiced in architecture and the related arts."[5]

1 See the chapter Fabric Formwork for the development of fabric formwork, which is summarized here.

2 Kenneth Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, ed. John Cava, (The MIT Press, 1994/2001), 3. As summarized by Frampton.

3 Gottfried Semper, *Style in the Technical and Tectonic Arts; or, Practical Aesthetics: A Handbook for Technicians, Artists, and Friends of the Arts*, (org. Germ. 1860/Los Angeles: Getty Research Institute, 2004), 1. In the introduction to this translatied edition, the translator Harry Francis Mallgrave emphasizes the publication of Charles Darwin's *On the Origin of Species by Means of Natural Selection* (1859) and the first volume of Karl Marx's *Das Kapital* (1867) as two studies that launched revolutions on their respective fronts.

4 Kenneth Frampton, "Rappel à l'Ordre: The Case of the Tectonic," in *Labour, Work and Architecture*, vol. 1990, 60 vols., Architectural Design 3/4 (Phaidon Press, 2002), 91-103.

5 Ibid., 93.

In her doctoral dissertation about the tectonic practice at the onset of the now present digital era of construction, the Danish architect Anne Marie Due Schmidt criticizes the focus of Frampton, and representatives of 'traditional tectonic discourse', on architectural ideals in terms of the architectonic edifice since architecture is *"much more than what meets the eye. It is also a practice that draws on technology and develops ingenious solutions in the process of creating our urban and architectural environments – it is a tectonic practice"*[6]

Elaborating this definition, the empirically based methodology presented in this dissertation can be categorized as an 'experimental tectonic practice' as a category under research through design.[7] This means that experimental data is developed through a pragmatic and intuitive approach to tectonics through making. It is thus close to the 'structural and material probity' of the historical writings of Semper. The analytical studies are shaped as studies of the 'tectonic practice' and of the 'tectonic object', though they will be named differently. From the reflections of the practice and from findings from analytical studies it is the aim to contribute to tectonic discourse with an aspect of poetics of concrete construction through the study of the tectonics of formwork.

Technology and becoming

The Greek word *techné* is relevant for the architectural context of this dissertation because it represents artistic as well as instrumental aspects of technology. Technology is a means to an end, and technology is a human activity.[8]

The material workshop activities that generate the data in the present project could be seen in a similar light. The assertion, then, is that research of technology through experimental architectural practice constitutes fruitful, parallel and overlapping research approaches.

In this dissertation, initial concepts and reflective aspects and notions of materials and structures belong to the rhetorical side of technology. Concepts of a technical nature are described as *principles.* When the word *symbolic* is used it refers to the transfer of an aspect of a textile notion, particularly a decorative aspect.

The thread of the dual-sided view on technology, i.e. logos of techne and techne of logos as introduced by the architectural theoretician Marco Frascari, will be applied in the development of an understanding of textiles as surface and structure as well as of architectural concrete. The scope of investigation is shaped as a thematic examination where design and construction procedures as well as the structural applications of concrete overlap. One reason for this is the wide array of scales of applications of textiles in architecture and construction; another reason is to qualify the suggestion that the different purposes for research in fabric formwork reflect the same threads in the evolutionary development of the use of concrete.

The German philosopher Martin Heidegger discusses 'Createdness' as belonging to the 'work' that leads to the work of art – "to create is to let something emerge as a thing that has been brought forth. The work's becoming a work is a way in which truth becomes and happen."[9] The architectural practice of designing the resulting form and structure, and the significance of the specific materials and techniques to achieve this is what that Martin Heidegger might call procedures of *be-coming* a work of art, something is brought forth.

This theme of becoming is the subject of a theoretical model for a sculptural work of art

6 Anne Marie Due Schmidt, "Tectonic Practice – in the Transition From a Pre-Digital to a Digital Era" (PhD-Dissertation, Department of Architecture and Design, Utzon Center, Aalborg University, 2007), 3. The dissertation investigates the development and use of tools and materials for the construction of two stages of the Sydney Opera House by Jørn Utzon.

7 Bruce Archer, "The Nature of Research," *Co-design, interdisciplinary journal of design* (January 1995): 6-13; Christopher Frayling, "Research in Art and Design" 1, no. 1, Royal College of Art Research Papers (1994 1993): 1-5.

8 Heidegger, Martin. "The Question Concerning Technology", (org. Germ. 1954) in *Basic Writings : from Being and time (1927) to The task of thinking (1964)*, 307-342. (New York: HarperCollins, 1993), 312.

9 " Martin Heidegger, "The Origin of the Work of Art" (org. Germ. 1935), in *Basic Writings,* 185.

10 Willy Ørskov, "Objekterne - Proces og Tilstand: forslag til en objektteori," in *Samlet : Aflæsning af objekter, Objekterne, Den åbne Skulptur*, Antology of writings. (Borgen, 1999), 126. The model is illustrated in the chapter *Theory and Concepts*

by the Danish sculptor Willy Ørskov.[10] To Ørskov the becoming of an art-object is understood over time as a series of conditions. The model is used in the disseratation to evaluate traces of these procedures of becoming that are evident on the surface of the concrete object. Concrete structures show traces of the preceding processes, and at the same time it has a sensible tactility and expression; it is a material. Returning the dual sides of technology, the becoming of concrete relates to the instrumental and creative actions and decisions of the maker - in this regard, technology is seen as "*a reality acting between sensory experiences and physical expressions, being the union of the* homo faber *with the* homo ludens*. Technology is a subjective presence rather than an objective procedure to which the client and architect must be subjected.*"[11]

Material and process

As stated by the Scottish professor and teacher Remo Pedreschi at the Edinburgh School of Architecture and Landscape Architecture (ESALA) the process of fabric-forming "*reveals a synergy between the fabric and the fresh concrete. The concrete gives shape to the fabric by its weight and then receives the form and surface the fabric produces in return. The research must deal with the dichotomy of form and process.*" and he continues in stating that the research methodology "*endeavours to continually shift perspective between form and process, between expressiveness and rationality*."[12]

The attempt at carefully describing the processes and naming the common technological denominators of a new practice of fabric forming has overlapping theoretical and practical aims. The theoretical aims have are related to architectural theoretical discourse for textiles and concrete.

Textiles

For textile the theoretical aim relates specifically to the categorization of textile roles in fabric formwork. The textile is a new formwork material. This is investigated in relation to the technological transfer of textile notions and principles to the construing and construction of concrete structures.

Textiles in the dissertation are viewed as surface, as structure, and as symbol. Here, a hypothesis of the dissertation proposes that a range of potentials are present in dual-sided textile roles in fabric in the construing and construction of fabric formed concrete structures, and that architectural potentials of fabric formwork lie in the understanding achieved through the localization and formulation of textile categories and textile roles.

The hypothesis is addressed through the following research question:

Based on an understanding of architectural technology, which and in which ways may textile principles transfer to concrete construction when used as formwork?

The aim is to contribute substantially to the foundation of a theoretical discourse for textiles in fabric formwork. Textiles, in the current state of the art, have mostly been described in terms of natural science or of acts of making architectural prototypes.

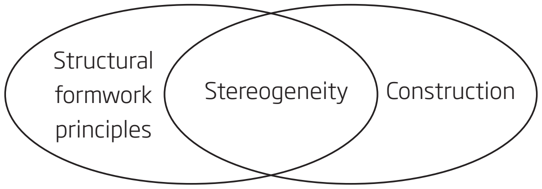
11 Marco Frascari, *Monsters of Architecture* (Rowman & Littlefield Publishers, 1991), 115.

12 Remo Pedreschi, "Dialogues in Process and Form – Studies in Fabric Cast Concrete ", in Alan Chandler and Remo Pedreschi, eds., *Fabric Formwork* (RIBA Publishing, 2007), 23

13 With assistance from the Greek author Iosif Alygizakis

14 Remo Pedreschi, "Dialogues in Process and Form", 24.

15 The verb concreting is borrowed from concrete contractors. In this dissertation the verb covers the applications of concrete via pouring, spraying as well as by hand.



A specific expressed stereogeneous quality can occur for concrete when the careful development of formwork principles and the procedures and materials of construction and concreting overlap.

Concrete

The individually designed concrete objects made during workshops are sculptural and expressive of their becoming. In addition to these decorative and formal aspects for concrete as a material, the experimental data makes it possible to describe concrete as a process. Analytical studies further elaborate the tectonic terminology involved in the rhetorical and instrumental construction of concrete. With a deeply rooted architectural vocabulary at hand, the tectonic understanding of fabric formwork and fabric-formed concrete point towards practical applications in contemporary construction.

In order to study concrete as conditions over time, a specific concept is established to embrace concrete as an architectural material. The term *stereogeneity* describes concrete as a material *and* as a process. The concept has emerged gradually during the thesis work, in response to a pronounced quality of fabric-formed concrete and an apparent gap in existing theory within tectonics to embrace this duality of, on the one hand, the experienced, sensed qualities of a cured concrete structure as material and, on the other, the processes that leave almost metaphysical traces of becoming that may be the most poetic feature of concrete. Derived from the Greek adjectives *stereos,* solid, and *ginomai,* to begin to be, it is a word and a concept coined by the author.[13]

The concrete objects in this dissertation are described as structural typologies and explained via their process of construction,[14] and evaluated through an analysis of the roles of their formwork details upon the stereogeneous consequence. A formal definition of the concept of stereogeneity is suggested here as "*the expressed manifestation into solid material form of a series of conditions, from the construing and construction of structural formwork principles, and concreting.*"

The suggested relation between concrete and its mold is expressed through the following practical hypothesis for fabric-formed concrete: A direct stereogeneous consequence arises from the relationship between the structural formwork principles of the textile, the form tie, and the frame; and from the procedures of construction.[15] For the stereogeneity to have a poetic significance, however it must occur in the overlap between the careful correlations of principles, procedures and materials as illustrated to the left.

The pragmatic aim is to suggest a strategy for the implementation of a new formwork technology in architectural practice through the concept of formwork tectonics and stereogeneity as a way of thinking and doing concrete architecture.

In this regard:

How do new principles for the construction of fabric-formed concrete, when leaving traces of its making, inform the architectural vocabulary of concrete
- and how may the expressed principles and procedures of construction inform the understanding and use of concrete as material and process?

The direct stereogeneous consequence from the formwork tectonics of fabric formwork lead to another hypothesis for the 'old' formwork elements, the frame and the form tie.

When traditional construction elements, the frame and the form tie, are expressed in the cured concrete structure, particular aspects of making are expressed in construction. This will lead to new rhetorical and technical roles of formwork elements for concrete.

It also frames the practical application and it is suggested that *new roles of traditional elements of construction act as 'common denominators' of artistic and practical significance and lead to implementation in contemporary construction.*

Details

Marco Frascari argues that "*the detail expresses the process of signification; that is, the attaching of meanings to man-produced objects. The details are then the locii where knowledge is of an order in which the mind finds its own working, that is, logos.*"[16]

Frascari's interest in details as signifiers in architectural production frames key elements of this dissertation. The experimental data constitutes the material evidence of condensed architectural production during architectural experimental workshops; both the constructed formwork principles and the concrete results can be considered details in Frascari's sense.[17]

In the categorization of structural typologies of concrete objects and formwork structures for more than 40 experiments, the *frame*, the *form tie*, and the *textile* are considered the core elements of fabric formwork. Analytical studies of the experimental data are thus the simultaneous a study of detailing in formwork structures and, as Frascari argues, of the minimal units of signification in the architectural production of meanings.[18]

Potentials

The combination of the formwork tectonics and the stereogeneous consequence defines a study within the field of Poetics of Construction. In this light the dissertation will aim to support the hypothesis that the careful study of individual formwork elements for fabric-formwork concrete structures will reveal a poetic potential for concrete.

This dissertation is not a philosophical enquiry into the *essence* of the technology of fabric formwork in a Heideggerian sense. It is important to note that it is an architectural mode of enquiry, which proceeds through experiments and the craft of making, followed up by reflections and dissections of the processes and resulting materials – and their potentiality for creating architecture.

Aristotle's definition of potentiality compares the *generic potentiality* of the child, who *has* the potential of becoming knowledgeable through an alteration, to the *existing potentiality* of the knowledgeable architect, who *is* potential and does not need to bring knowledge into actuality through the alteration of building a house, as interpreted by the Italian philosopher Giorgio Agamben. He compares the Italian word for [can] *potere* with potentiality and actuality and establishes a link with cannot and a potentiality for not-doing.[19] An example of the non-ability of vision is to *see darkness*. And the potentiality of hearing is thus to hear silence.[20]

The potentiality of concrete 'vision' is not too 'see' fluidity of solid. The interpretation of potentiality of doing and not-doing in the present thesis is rather more pragmatic. Perhaps an understanding of fluidity in *process* of construction rather than rigidity may be applicable to fabric formwork. If practitioners of concrete architecture, builders, consulting engineers, and architects, will simply have the qualifications to select the most appropriate method of construction if they are aware of the fullest range of techniques. The aim is to supplement the toolbox of existing principles of making with a few extra applications of basic elements of construction. Fabric formwork is a simple tool, so is also an adaptable tool. It means, however that different techniques must be acquired in order to utilize this aspect.[21]

16 Marco Frascari, "The Tell-The-Tale Detail" (1984), in *Theorizing a New Agenda for Architecture: an Anthology of Architectural Theory 1965-1995*, ed. Kate Nesbitt (Princeton Architectural Press, 1996), 500.

17 Ibid., 501. Frascari argues that a definition of detail in dictionaries as part in relation to a larger whole is not valid in architecture, because a column can be considered a detail as well as a whole. Any architectural detail is always a joint, either a 'material' or a 'formal' joint.

18 Ibid.

19 Peter Bertram, "Den animerede bygning " (PhD-Dissertation, RDAFASA, 2008), 6. In his PhD dissertation about architectural methods and media of making, the Danish architect Peter Bertram introduces Agamben's potentiality of not-doing. Bertram compares architectural knowability with potentiality and asks "*can an ability exist? Can that, which only exist because it is made, be considered to exist?*"

20 Ibid.

21 Richard Sennett, *The Craftsman* (Penguin, 2009), 198. Sennett uses two types of screwdrivers, the Philips head screwdriver and the flat-edge screw-driver, as an analogy of fit-for-purpose tools vs. simple tools. The Philips head is easy to use for a specific purpose. The straight edge screwdriver requires learning different techniques but can then also be used as a gouge, an awl, or a cutter

METHODOLOGY

Experimental architectural practice
Analytical investigations
empirical Investigations
Theories of questioning
Critique of approaches

EXPERIMENTAL ARCHITECTURAL PRACTICE

Fabric formwork in an experimental tectonic framework.

Fig. 1. Students working at the ESALA workshop. (Photo from ESALA student report)

Fig.2. Plaster models at CAST (Photo: Allison Adderley)

This architectural investigation of fabric formwork for concrete structures grounds itself methodologically in an open-ended field of experimental and intuitive practice defined by material notions and properties of concrete, formwork, and textiles. Within this framework, the attempt is to lay out an overall tectonic kit of parts for fabric formwork for the construing and construction of fabric formed concrete structures.

This chapter will introduce the practice by two leading environments for architectural research in fabric formwork, which have informed the present methodology; describe the process of the empirical investigations and process and theories of the analytical investigation; and finally offer a critique of the selected methodology.

The cutting-edge research in fabric formwork in schools of architecture[1] is consistently based on an experimental material practice. The following two are especially influential to the methodology of the project and the value assigned to the prototype of which the English architect and teacher-researcher Alan Chandler states:

"*Building at 1:1, informed by with a limited but effective body of intuition and understanding, provides a broad platform from which significant areas of study – materiality, of process, of technique, can be tested simultaneously. It is only after the prototype is built that the scientific model of analysis becomes vital in refining the opportunities that full scale making has generated. The prototype tests the interaction of materials and events, not merely their constituent parts. In building a prototype, one discovers how to build, and where to focus the activity of risk, the value of team consciousness, and the consequences of theoretical decision making.*" *

Research at the University of Edinburgh

The teaching and teaching practice developed in the present dissertation is inspired by the research-teaching practice at the Edinburgh School of Architecture and Landscape Architecture (ESALA) of the University of Edinburgh, where students achieve an understanding for the principles of fabric formwork and develop methods with a focus on the pragmatic aspects, the nature of the connection between concrete elements cast in fabric formwork, and rationalization.[2]

The students do not work in plaster models but only use different procedures of concreting.[3] The results of five-week studies are described in written and illustrated reports by the students. The empirical work forms the basis for further research.[4] (Fig 1)

Centre for Architectural Structures and Technology

The research practice at CAST, the Centre for Architectural Structures and Technology at the University of Manitoba is significant, because it is the first and only dedicated research center that focuses exclusively on fabric formwork for concrete. The 'shotgun' method[5] is the production of numerous small-scale plaster experiments in which specific structures are 'found.' (2)

The method resembles firing a shotgun against a wall and later drawing the bull's-eye

* Chandler and Pedreschi, *Fabric Formwork*, 19

1 The RIBA President's Award for Research 2008 was presented to Remo Pedreschi of the University of Edinburgh and Alan Chandler of the University of East London for University-located Research for their work on Fabric Formwork in collaboration with the Centre for Architectural Structures and Technology (CAST) headed by Mark West of the University of Manitoba. http://fabricforming.org/news_fabric_formed_curtainwall.html (accessed 2011-09-20)

2 Chandler and Pedreschi, *Fabric Formwork*, 22.

3 Remo Pedreschi in his lecture at the First International Conference on Fabric Formwork, Winnipeg, Manitoba, Canada: CAST, University of Manitoba, 2008). Students get the choice to work in plaster but they enjoy concrete.

4 Chandler and Pedreschi, *Fabric Formwork*, 18."The extension of fabric formwork research into structural, thermal and acoustically active structural slabs commenced in 2006–7" and Daniel Sang-Hoon Lee's PhD project about a construction method for producing the "form-efficient fabric-formed concrete beams" that are subject for analytical studies later in this dissertation.

5 Steven Vogel, *Life in Moving Fluids: Physical Life of Flow*, 2nd ed. (Princeton University Press, 1996), 3. West refers to the 'shotgun' analogy which Vogel uses to describe his own research methodology in biology.

around hits. The next stage is to further examine the findings in full-scale prototypes, which in turn form the basis of collaborations with concrete factories and architectural firms.

West elaborates on the nature of the 'shotgun' method and the focus on materials and form:

> *"By playing we can find the forms that are given to us by the materials themselves and by the actions and the materials themselves. So we work backwards from a normal design methodology."*[6]

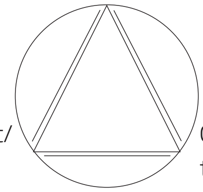


Figure 3. Possible generators of empirical data through experimental pedagogic work (workshops). Model based on the figures of Didaktik in (Hopmann 20)

Experimental Data

Empirical data for this thesis is produced through open-ended architectural experiments (workshops).

The nature of the research represents methods used at ESALA and CAST. In line with ESALA workshops with students are held to produce the basis of further investigation as well as the production of reports. Learning from CAST come the initial tests with plaster models. Mark West argues that if they can produce a structure in 1:10 in plaster, they guarantee to be able to produce it in full scale with concrete.[7]

Students who participate in short workshops are introduced to this argumentation of causality but also with the consequence for the reverse result, that is to say mistakes and fails in the small-scale work also ndicate the behavior at a larger scale. In other words, if dimensioning or detailing cause a formwork principle to fail in a small-scale model, it is very unlikely to succeed in full-scale.[*]

The 'results' of the workshops are full-scale concrete objects, but these objects are supplemented with more comprehensive experimental data. Sets of experimental data come in the form of reports consisting of the documentation of the process in selected drawings, reflective or descriptive writing as well as photos of procedures and structures, and final material objects. The reports and the experimental data of the workshops are produced by the students who responded to the workshop assignment.

The empirical data made by the author were thus produced by the author herself or by students participating in the workshops, which she organized and taught.

The TEK1 workshops cover an approach described in pedagogical science as an experimental mode of Didaktik[8] or educational experiments. Data can be drawn from three levels of a basic model of Didaktik. It expresses the relationships between the teacher/organizer, the student/participant, and the result/process. [9] (3)

One aim of the workshops in the thesis work has been to achieve architectural approaches to the development of basic structural principles for fabric formwork. The resulting experimental data of the workshop, in the scope of this research, is thus a combination of principles, process and concrete form.

For architectural workshops these categories of data can be selected in a material form: The experimental data from the workshops are compiled in a report form, produced by the participants, which Frayling and Archer describe as *action research*.[10] Action research becomes valid as research because processes and reflections are communicated in a resulting report that is compiled and contextualized from step-by-step studio diaries.[11]

Action research is almost always situation-specific,[12] which is also the case for the series of

6 *Heavy Light - Fabric-Formed Concrete Structures* (ETH, Zürich, Switzerland: Institute of Technology in Architecture, Building Structure, 2011), www.youtube.com/,(Accessed 30-10-2011). The methodology is described further in the analytical study of the *Fabric-Formed Rigid Mold.*

7 "What I've learned over 20 years of doing these experiments is that *anything* that you can build with a little model with light fabric and plaster, you can build much larger with industrial fabrics and concrete." Mark West, lecture, Chalmers, November 2009. This basically means that poured models are always 1:1 and this relation can be noted in several examples in the appendix.

* This is especially evident in the TEK1 2010 workshop (appendix 6) where the assignment called for 2-meter formwork structures.

8 Stefan Hopmann, "Restrained Teaching: the common core of Didaktik," *European Educational Research Journal* 6, no. 2 (2007): 114. Hopmann traces the word Didaktik to Classical Greek, the group of words connected to '*didaskein*', i.e. teaching, showing something, playing out a drama (p.110) i.e. teaching, showing something, playing out a drama.

9 Ibid., 115. Hopmann describes developments and culturally different practices to using the didactic model in teaching in schools and describes the common core of Didaktik as 'restrained teaching', based on (a) a commitment to 'Bildung' , (b) the educative difference of matter and meaning, and (c) the autonomy of teaching and learning. He explains the German word Bildung here to combine elements of education, erudition, formation, experience, and whatever else is used in English to denote the process of unfolding individuality by learning.

10 Christopher Frayling, "Research in Art and Design" 1, no. 1, Royal College of Art Research Papers (1994 1993): 5.

11 Ibid. For the present thesis work this is achieved by students through writing, scanned drawings and photographs of structural details and of the active participants

12 Linda Groat and David Wang, *Architectural Research Methods* (New York: Wiley, 2002), 111.

workshops where part of the assignment for the participants is the compilation of experimental data. Each experiment is in itself an example of this action research. This is illustrated as black squares in figure 4.

ANALYTICAL INVESTIGATIONS

The qualitative nature of the experimental data is validated through two phases of categorization.

A. Categorization and naming of the formwork elements and
B. Interpretation and comparison of rhetorical and instrumental roles of these formwork elements in regard to the signification of concrete/stereogeneity.

The principles and procedures within the two categories are then discussed with regard to their 'consequences' or potentials for concrete construction and their sensed potentials in concrete architecture.

More than 40 individual experiments were carried out in the three types of experimental practice that the author (AMM) either organized and taught, or participated in and which will be introduced a little later.[13]

The analysis, categorization and interpretation of experimental data have taken places as a continuous iterative process illustrated and described on the next page (fig.4). During the hermeneutic feedback loop between individual workshops, theoretical concepts have been articulated and further clarified and fed into the next formulation of an assignment brief. The workshops are illustrated as triangles that illustrate figure 3.

Initial categorization

The initial procedures of data categorization were performed based on the descriptive aspects of the data set. Descriptive aspects include concrete typologies and formwork typologies. The existing concrete typologies are simple to define, such as columns, walls etc.[14] Formwork typologies are less simple to define for fabric formwork because they display interplay of different formwork elements. Instead, an attempt has been made to categorize these elements as types or structural roles: the frame, the textile, and the form tie.

The typological table (the large chart in the appendix) has been altered over time, as the original categories proved too rigid to include the actual structural principles. It caused confusion to map objects that were described as one concrete type but constructed as another. This led to an increased differentiation between formwork elements and less focus on conventional concrete construction procedures.[15]

Studies of frame, form tie and textile

The second analytical approach relates the structural principles, and the stereogeneity of the constructed object; as mentioned in the introduction, a model by Eduard Sekler,[16] which relates structure, construction, and the tectonic, inspires this approach.

The selection of seven experimental cases is based primarily on the significant use of the frame, the textile or the form tie as a structural formwork element with a stereogeneous consequence. The secondary factor for choosing cases has been the representation of structural concrete typologies and concreting procedures.[17]

13 In workshops arranged by others, only the author's contributions are included as evidence.

14 The original table presented at the halfway-critique meeting in April 2010 included the following types: column, beam, slab, walls, and shells. The most important alteration has been the addition of the category of 'other';at times this goes under the term 'sculptural object,' which refers to the same meaning.

15 An example is the *Ambiguous Chair*. The concrete objects in this experimental series were originally listed both as 'wall' *and* 'shell' because the objects were cast as one would cast a wall, but they were experienced as more shell-like, tipped with cantilevered seats. The formwork for the objects was listed as 'frame.' In the refined typology, the concrete objects of *Ambiguous Chair* are listed as 'sculptural objects,' and the rigid formwork element as 'rig.'

16 Sekler, Eduard, "Structure, Construction, Tectonics."

17 West, *Heavy Light*. Concrete poured vertically, horizontally, and 'padded.' In this lecture Mark West defines this form of shell-casting by hand as the low-tech version of spraying concrete in an industrialized process

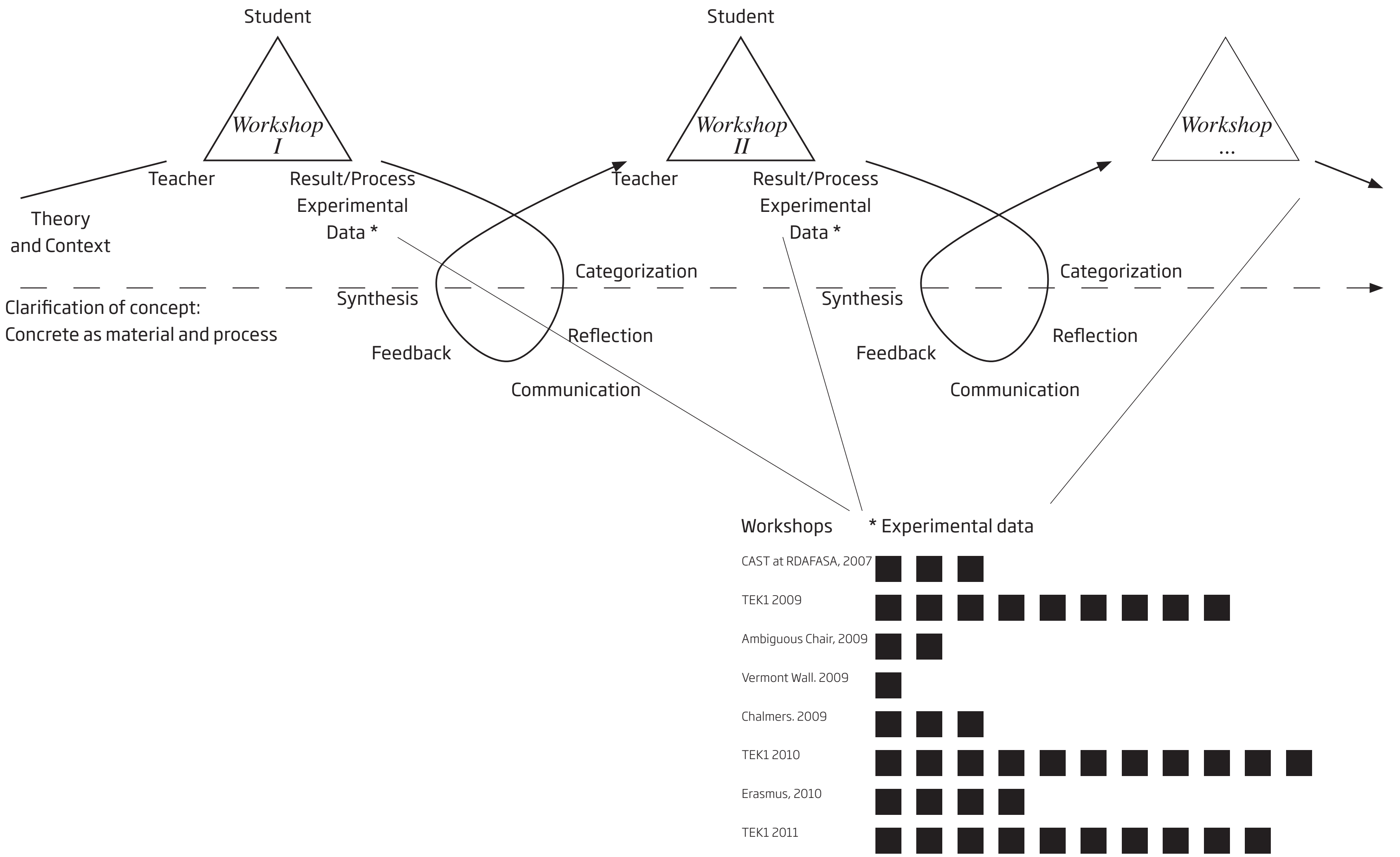


Figure 4
Qualitative methodology - research through design
The figure illustrates tje interdependency between actors within the feedback loops of the research practice: The top loops/Didaktik triangles generate knowledge through making.

The bottom feedback loops illustrate the creation of knowledge through activites between workshops, i.e. categorization, reflection, and communication.

The clarification of concepts undergoes ongoing development between and during the course of workshops & experiments; oral and written presentations; and analytical studies.

The analytical studies of specific experimental data applies the Janus-faced Greek view on technology, as *techne of logos* and *logos of techne* i.e. rhetorical and practical roles, as introduced by the architectural theoretician Marco Frascari.

Each analytical study elaborates on the multiple technological roles of the formwork element and includes descriptions of the structural formwork principle, a description of the construction process, and an analytical description of the concrete object in regard to its stereogeneity. The stereogeneity refers to the sensed expression of the concrete object as material and form and its displayed 'traces of becoming.' In other words, the analyses attempt to draw conclusions about the rhetorical and instrumental role and the effect of the significant formwork element on the sculptural form, structure and surface of the concrete object.

The analyses attempt to connect the visible and interpretable traces of 'becoming,' which can be found in concrete objects cast in fabric formwork with the careful construing and construction of the formwork technology. It will be argued that a 'poetics' of concrete can be formulated as the stereogeneous consequence of a particular relationship between formwork tectonics and concreting procedures.

Research field

The technological view of notions and principles has also shaped the basis for the overall view of fabric formwork, concrete, and textile. Thus, the initial chapters do not offer a linear introduction to the research field that follows the chronological history and development of fabric formwork; instead it presents fabric formwork as part of an evolution of concrete through the agendas for building with concrete and the significance of formwork tectonics and stereogeneous thinking. Likewise for textiles; the influence on the textile potentials in fabric formwork is suggested to stem from both the recent development of textiles in construction[18] and an aim of locating textile notions and principles used in concrete construction.

Fig 5. Pour day on the quay at RDAFASA. Formwork structures for fabric-formed walls at TEK1, 2010

Fig. 6. Bench (appendix 2.7)

EMPIRICAL INVESTIGATIONS

The experimental data forming the foundation for analytical studies has been developed through four categories of experimental practice:

A. Experiments organized and constructed the author (AMM)
B. Experiments in workshops organized by the author and undertaken by students
C. Experiments in workshops organized by others and constructed by the author
D. Experiments organized and constructed and by others

A. Experiments organized and constructed by AMM

Bench, TEK1 2009

The structural formwork was created toward the end of TEK1, 2009 as a response to the principles developed by students during the workshop. Identical legs were restrained with distinct block-outs. The seat was constructed with reference to work at ESALA. Here methods to produce T-beams included flange and web (the 'fin' under the seat). Due to the short time available for conception and construction, many details could subsequently be improved. (6)

18 Chandler and Pedreschi, *Fabric Formwork*, 7.

Ambiguous Chair, 2009

The *Ambiguous Chair* series was constructed as a objects for a specific context, a special exhibition at a Danish construction trade fair. The aim was make a surprise encounter for the professional and laymen observers at the construction fair. (7)

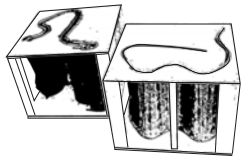


Fig. 7. The Ambiguous Chair

Composite Column, TEK1 2010

The formwork principle for the Composite Column is a specially made wood-textile. The approach of this experiment can be compared to the *Chalmers Column*, as it also explores the use of textile as a structurally embracing element, and because it also had formwork in two interrelated layers with different material properties. (8)

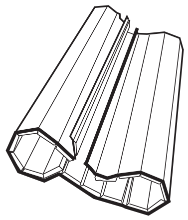


Fig. 8. The Composite Column (composite wood-textile)

B. Experiments by others in workshops organized and taught by AMM

The TEK1 workshops are a series of workshops for first-year bachelor students of architecture, organized by the author and colleagues at the Institute of Technology.[19]

The TEK1 workshops roughly followed this formula.

- First afternoon, brainstorm sketching in groups followed by a presentation and critique after one hour. Ideas and principles produced in 60 man-hours are now common property for all student groups.
- Second afternoon, groups devise a structural formwork principle and construct a 1:5 model in plaster.
- Day three, presentation and sharing of experiences and reflective findings. Groups refine their construction principle for their formwork and begin the making of 1:1 formwork structures as well as start a storyboard.** (9)
- Day six, the formwork structures are moved from the workshop at the Technical University of Denmark to the site on the campus of the RDAFASA.
- Day seven, the pour
- Day eight, stripping the formwork
- Day nine, handing in the report, 5-10 pages

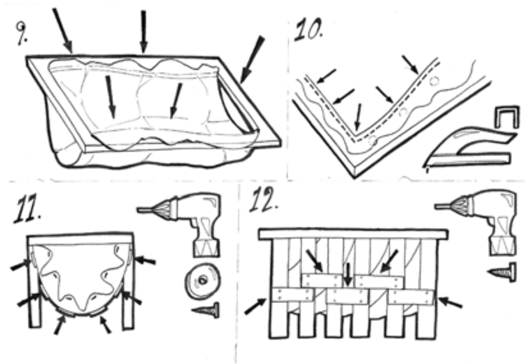


Fig. 9. Steps from storyboard for the construction of the *Rope Bench*, appendix 8.9

As illustrated in figure 4 on the previous spread, the setup for each workshop has been similar, but the assignments were different with regard to their immediate content and overall complexity, defined by the course faculty. Another difference is that the levels of active and passive knowledge[20] increased over time for the organizers and the participating students.The organizers increase their level of 'active' knowledge simply through experience. Next year's students have access to 'passive' knowledge through communication from the workshops through digital medias, lectures, and previously participating students; the concrete objects left on site set a new standard for pre-existing knowledge for the next class of students. The reflection loops (of the author) between workshops included increased compiling of theory as well as cultural and pedagogical reflections.

19 Johannes Rauff Greisen and Finn Bach

** The storyboard was introduced after the first workshop. It is step-by-step drawings of procedures and details of construction. Some groups made it before the construction and other during or after the construction of the formwork structures. the idea is to design the process as well as the concrete object and anticipate the fact that the formwork cannot be disassembled in the same way as it was built if concrete is poured over screws

20 Marco Frascari, "The Tell-The-Tale Detail," 506. Frascari describes how Scarpa had a 'passive' understanding of Wright's architecture through photos and drawings and an 'active' understanding of Veneto craftsmanship through his daily work and his experiences from dealing with craftsmen.

Participants in concrete furniture cast at the Erasmus Summer School 2010. An old garden for a school of ceramics was one of three sites for fabric-formwork. (appendix 7)

10

Three Columns at RDAFASA, 2007. The *Sinus Column* is (right) is subject to further analysis.

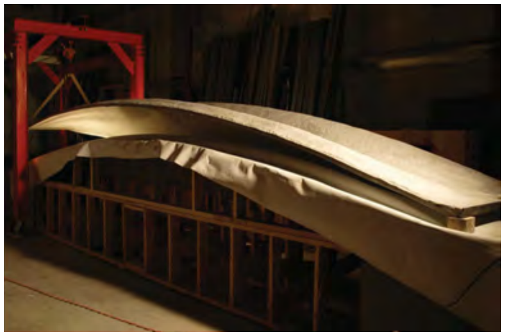
14

The *Chalmers Column* (appendix 5)

11

Form-Efficient Beam (Type 1) by Daniel Sang-Hoon Lee. Will be further analyzed

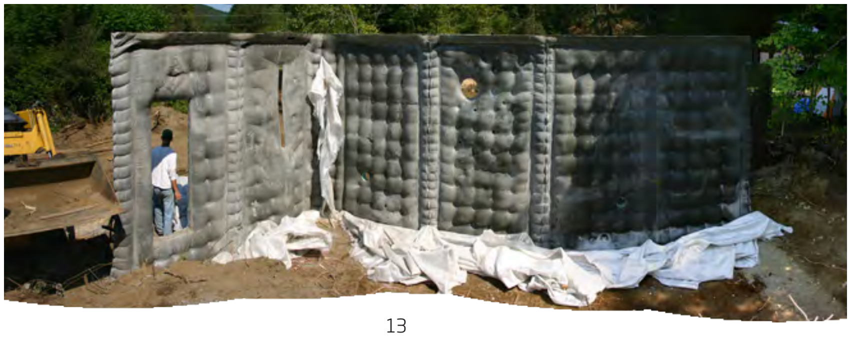
16



Fabric-Formed Rigid Mold and a thin concrete shell cast in the mold. CAST, 2009

15

The *Vermont Wall*, ISOFF workshop, Vermont USA, 2009 . See appendix / 4.



13

Tying carbon grid reinforcement during the construction of the L-shaped wall in Vermont, 2009. Notice the transluscent geotextile, from the manufacturer Fab-rene, which offered improved working conditions.

TEK1, 2009

The topic of the workshop was edges and curves. The students for this assignment were asked to investigate the properties of textile and plywood of different thicknesses. The exploitation of the mutual relationship between materials when used as formwork called for a variety of responses. Structural objects would be virtually impossible to predict. The maximum volume for the molds was 1-200 liters. (Appendix /2)

TEK1, 2010

The brief here stated the dimensions of the object: 200 cm high and with a maximum volume of 250 liters of concrete. The brief basically demanded a wall, while additional instructions demanded the investigation of restraining principles. (Appendix /5)

Concretum, Erasmus Summer School, 2010

Bachelor students from eight European architecture schools participated in this two-week workshop held at Bornholm.The brief for the "Concretum" workshop[21] included four different sites and thus expanded the formwork tectonic task with elements of scale and context. (Appendix /7). (Fig.10)

TEK1, 2011

The brief demanded a bench; thus expanding the formwork tectonic task with a functional task. The underlying purpose was to give the students experience with generating a long concrete structure. The expectations were not met in the sense that the originally envisioned structure was a simple long plinth that would relate to a beam. Few students focused on structural principles; when asked to design a bench, the students focused on seating and sculptural objects that would enable different ways of sitting and engaging socially and in regard to the site. (Appendix/ 6)

The first two workshops have formed the most important part of the experimental data because of the content as well as the time of the workshops during the first half of the thesis work. The last two workshops will be discussed further at the end of this chapter.

C. Experiments in workshops organized by others and constructed by AMM

Chalmers Column, Concrete Flesh 2009[22]

The formwork principle for the *Chalmers Column*[23] explored behaviors caused by an approach of relaxation and restraint.

The project explored properties and behaviors of an inner elastic membrane, an outer net membrane, and restraints made of circular disks with varying diameters.

Cuts were made in the embracing net, which allowed the spandex to bulge out. The embracing net was held together with 'rope laces' and suspended from a tripod structure.

Vermont Wall, ISOFF Workshop Vermont 2009.[24] A wall was constructed using the URC quilt-point method. Organizational and cultural aspects of the workshop, its setting in the rural

21 Peter Sørensen, ed., *Tectonics in Building Culture: Concretum*, (Copenhagen, Denmark: RDAFASA, Institute of Architectural Technology, 2011). The workshop was organized by Peter Sørensen of the RDAFASA who hosted the summer school. The assignment was organized by AMM and Peter Sørensen.

22 Morten Lund, Sanna Nordlander, and Karl-Gunnar Olsson, eds., *Concrete Flesh - Matter Space Structure Studio Workshop November 2009* (Gothenburgh, Sweden: Chalmers University of Technology, Dep. of Architecture, 2010). See appendix 5

23 Frederik Petersen, "Repræsentationens realisering (Realisation of Representations)" (PhD-Dissertation, Aarhus School of Architecture, 2011). The experimental work was conducted with architectural PhD student Frederik Petersen, Aarhus School of Architecture, and Norwegian architect Kathrine Næss. The work is also discussed in Frederik's dissertation.

24 See appendix, workshop 4.

Vermont was especially interesting. First of all because the role of AMM was as a participant and not also an organize, secondly because of the conversations and exhange of experiences with fellow participants.*** (Figure group 13)

D. Experiments organized and constructed and by others

The *SInus Column* was constructed as part of Three Columns at RDAFASA in 2007 by researchers from CAST. AMM assisted. See chapter Analytical studies of the frame and appendix /1. (14)

The *Fabric-Formed Rigid Mold*[25] is an experiment by researchers at CAST. Here a specially made composite textile is manipulated to form 'pull-buckles' and made rigid using GFRC (Glass Fiber Reinforced Concrete). the rigidized corrugated shape functions as a rigid mold for repeated castings of thin concrete shells. (15)

The *Form-Efficient Beam*[26] is the topic of PhD research by the civil engineer Daniel Sang-Hoon Lee at the Department of Architecture at the University of Edinburgh, United Kingdom. A construction method using fabric formwork is developed and tested in 11 beams to make form-efficient concrete beams. (16)

THEORIES OF QUESTIONING

The following paragraphs will present a number of models for generating data and acquiring understanding in research through design and describe underlying aspects of the research in this dissertation.

Educational experiments

The model of Didaktik, illustrated before, is used in the field of educational research for the generation of experimental data. Experimental educational activities can thus generate a multitude of empirical data.
The figure describes relationships and processes between the organizer/teacher's existing knowledge or experience, the participant/student's presumed knowledge or experience, and the content/process.

In research in educational science, data can be drawn from each of these corners of the model and applied in the social sciences through a variety of methods[27] – the scope of this project defines the 'experimental data' as belonging in the 'process/result' corner of the model. Also, the active participation by the author generates important reflections and experience that belong to the 'Organizer/teacher' corner of the model.

The iterative process of generating experimental data through workshops thus reconfigures the value applied to all the legs of the model. The figure with feedback loops (shown before) indicates this; knowledge and experience feeds intro the Didaktic triangle for the next workshop or experiment. The developments and reflection of knowledge of the organizers and the reflection of the 'apparent' or 'assumed' knowledge of students and what they can 'accomplish' throughout the workshops 'set the bar,' so to speak, with regard to the complexity of the assignment for the next workshop.

25 Mark West, "Thin Shell Concrete From Fabric Molds" (CAST, University of Manitoba, 2009), http://www.umanitoba.ca/cast_building/assets/downloads/PDFS/Fabric_Formwork/Thin-Shell_Concrete_From_Fabric_Forms_SCREEN.pdf.

26 Daniel Sang-Hoon Lee, "Study of Construction Methodology and Structural Behaviour of Fabric-formed Form-efficient Reinforced Concrete Beam" (PhD-Dissertation, Department of Architecture, University of Edinburgh, 2011).

*** The host/organizer Sandy Lawton is an architect-builder who uses fabric formwork in a region where lightweight wood frame construction is the norm. Also Mark West and Roonie Araya of CAST participated in the workshop as well as the US structural engineer Robert Schmitz amd the Japanese architect Shuji Suzumori whose master theses was about fabric formwork. Shuji Suzumori, "Formwork as Design Tool" (Master Thesis, Architecture, Massachusetts Institute of Technology, 2002).

27 The Department of Education at the University of Aarhus categorizes science of pedagogigs as embedded in a reflective framework between history, society and philosophy. Aarhus University, "What is Pedagogigs?," Department of Education, 2012, http://edu.au.dk/en/research/. Practices of social sciences include monitoring the creative process or group dynamics by video or performing interviews.

The art of interpretation

Hermeneutics is the art or science of interpretation[28]

The German philosopher Hans-Georg Gadamer (1900-2002) was a student of Martin Heidegger, and his work can be seen as an elaboration of Heidegger's thinking. Gadamer wrote "Truth and Method" [29] on the philosophy of humanistic studies, which defines the contemporary hermeneutics in the humanist tradition. His thoughts about *foregrounding prejudice* and *fusion of horizons* address key aspects of the research methods applied in this thesis.

Gadamer's definition of 'foregrounding a prejudice by provoking and questioning'[30] can be read in the context of the workshop situation – it highlights one of the privileges of teaching first-year students. Namely that most of these students, naturally, have very little prior experience with studying architecture – including experiences with processes and conventions of construction using concrete. They enter into the workshop situation with a clear horizon, so to speak, and vague prejudices against construction with concrete. Students or practitioners who, on the other hand have previous experience – especially with concrete – would enter with a different horizon, a cloudy horizon, and with a certain prejudice.

This notion of prejudice and a narrower horizon in fact applies to the organizers of the workshops, which highlights another privilege of generating data through workshops. It is also part of the reason why assignments are designed in a fairly simple and open-ended manner, and in this regard it also frames the 'reciprocal'[31] nature of generating research through organizing and teaching workshops.

The essence of questioning, which is such a crucial activity in the humanities, is also an important part of the workshop situation – the students are literally asked to question the materials at hand and the possibilities inherent in the assignment. In this specific form of architectural research, this means questioning the essence of the dual-sided technology of fabric formwork, the possible construing and construction of formwork for concrete elements. In this sense, it is not questioning in the philosophical sense as such, but the line of questioning shares the open nature that is highlighted by Gadamer as the hermeneutic task. In architecture, and very clearly in the workshop format, the hermeneutic practice of understanding, interpretation and application happens and is simultaneously articulated through the practice of making. The experimental data report prepared by the participants serves to document the process.

The questioning in the analytical stages of the research project has a different aim and a different form. The construction of a theoretical body of architectural knowledge from the experimental data aims to understand and articulate an essence of the technology of fabric formwork. The analytical studies form one method of projecting the potentials, the future of fabric formwork in a contemporary construction of architecture.

The context of questioning is important; it is argued in this dissertation that the possible practical implementations of fabric formwork require the articulation of the scientific *and* symbolic significance of the components of the technology. A mutual understanding of the fundamental technological vocabulary of construing and constructing fabric formwork will facilitate an informed dialogue between architects and contractors. This supports Remo Pedreschi's argument that "*the true sense of a material comes from the ability of the observer to understand its nature from series of different perspectives.*"[32]

28 *The Cassell Compact Dictionary* (London: Cassell, 1998). Hermeneutics

29 Originally Wahrheit und Methode (1960).

30 "*Foregrounding (abheben) a prejudice clearly requires suspending its validity to us. For as long as our mind is influenced by a prejudice, we do not consider it a judgment. How then can we foreground it? It is impossible to make ourselves aware of a prejudice while it is constantly operating unnoticed, but only when it is, so to speak, provoked.*" Hans-Georg Gadamer, *Truth and Method*, 2nd rev. translation (London, United Kingdom: Continuum, 2004), 298.

31 Ibid., 304–05. "[*T]his idea of foregrounding … is always reciprocal. Whatever is being foregrounded must be foregrounded from something else, which in turn, must be foregrounded from it … We have described this above as the way prejudices are brought into play. We started by saying that a hermeneutical situation is determined by the prejudices that we bring with us. They constitute, then the horizon of s particular present, for they represent that beyond which it is impossible to see.*"

32 Chandler and Pedreschi, *Fabric Formwork*, 21.

An ambition of the work in this thesis is to mediate processes between an 'active' and a 'passive' understanding of construing and construction of fabric-formed concrete structures for architects and builders.[33] This distinction should be understood in the sense that the passive understanding of fabric-formed concrete may in fact include degrees of prejudice in relation to both concrete and fabric formwork, which would blur the intuitive understanding of the fundamental principles. On the other hand, with these construction principles, it should not be necessary for the experienced 'craftsman' of any of the professions in the construction industry to require any active knowledge before entering into this dialogue.

The categorization and interpretation of the significance of the experimental data about a novel construction technique draw upon an open-ended approach to questioning. When searching for the architectural potentials of fabric formwork the main task has been to articulate the right questions.

The line of questioning is an instance of revealing *prejudices*. The realization of ambiguity in the cataloguing process indicates that initially formulated formwork typologies need to be redefined. The reading and rereading of experimental data through the framework offered by the typological tables offers ways of producing *findings* that are essential in the development of any architectural practice.

The data and the objective are the same; it is the changing questions that offer new clarity and, ultimately, new insights.

CRITIQUE OF THE APPROACHES

Critical points can be raised toward these approaches to generating empirical data and the hermeneutic task of understanding and interpreting the data through questioning. First of all it can be questioned why the empirical data of an Industrial PhD is not obtained from these partners. The open-ended and intuitive/impulsive approach in the project allowed the involvement with projects undertaken at the the architectural practice and the contractor. Fabric formwork was discussed for a few cases, for example the construction of a large retaining wall in an amusement park in Copenhagen. As it turned out, this project fell through. Had the project come to be, then this dissertation had contained other categories of empirical data.

The role of the author as a participating teacher defines the scope of the workshop and supplies input and technique. The nature of architectural research through practice is however bound to be subjective.

The briefs for the assignments and elaborations in notw-form on the development of the TEK1 workshops are placed in the appendix and may serve as inspiration for future research of this kind.

In regard to the selection of experiments for analytical case studies, one might point out that the criterion for concrete structures that 'survived' the pour disqualifies structural principles in experiments whose formwork *blew* during the pour and did not fill. This is one of the circumstances that Archer mentions in the following.

33 This refers again to Marco Frascari's theoretical work.

34 Bruce Archer, "The Nature of Research," *Co-design, interdisciplinary journal of design* (January 1995): 10.

35 Seemingly, for me. Because I wanted to investigate specific structural types. For the Erasmus workshop, an assignment for a shelter for firewood would call for a concrete frame of a kind. For TEK1 2011, the brief for a bench was intended on my side to investigate ways of spanning.

"*[B]ecause Action Research is pursued through action in and on the real world, in all its complexity, its findings only reliably apply to the place, time, persons and circumstances in which that action took place. It is thus difficult and dangerous to generalise from action research findings.*"[34]

A benefit of this applied approach is that it limits the already large number of parameters to be studied and the amount of uninformed speculation. A second round of analytical studies could apply findings of the roles of the formwork elements for an informed assessment of the presumed stereogeneity of structures that did not 'survive' the pour during experiments.

The actual *concrete* data, the concrete objects, could have played a more prominent role in this thesis work and examinations for thermal, acoustical or spatial qualities.

In regard to the categorization and the analytical treatment of the data, a variety of possible approaches might have been taken. By including the summaries of the experimental data (the student reports) in the appendix, readers are invited to reconfigure the data and re-assess the essence of fabric formwork.

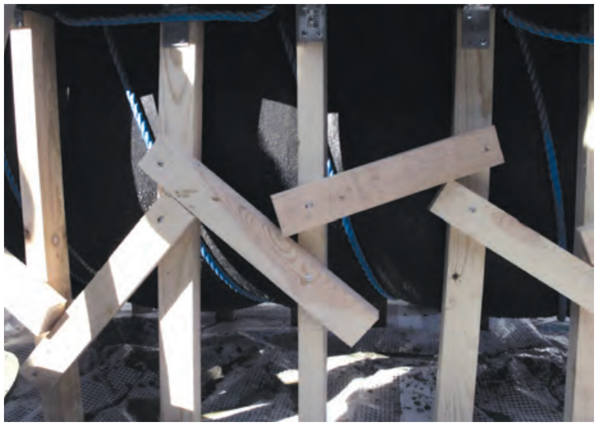
The Erasmus 2010 and TEK1 2011 workshops contained more parameters than the previous workshops.The additon of context and function to the workshop brief introduced aspects that are present in most architectural practice. The brief for Erasmus as well as TEK1 2011, for example, included assignments that seemingly invited to specific concrete typologies.[35]

The students, however challenged the brief, the architectural programme they were given, and with good reason. See the illustration of the *Wood Shelter*. For the scope of the present dissertation, however, the experimental data of these workshops provided many parameters. This is acceptable when the overall amount of experimental data is large. Here, the general formwork principles still add to a body of work and specific details can illustrate points made in regard to more novel formwork principles developed in more restricted assignment.

This lesson display the complexity of design through research, that is to say the complexity of designing restricted by formats or aims defined by research. Research through design can have a more open-ended character, thus emphasizing the search in research. This, at least appears to be the case when the empirical data is produced through teaching.

Wood Shelter at the Eramus Workshop, Concretum, 2010.
The response to the workshop assignment to built a shelter displayed a conceptural and very stereogeneous approach. The firewood was bundled and concrete was poured between the wood and a formwork membrane.






CONCEPTUAL FRAMEWORK

Concepts of technology and tectonics
Concrete as material and process
Textile as surface, structure, metaphor

CONCEPT OF TECHNOLOGY

The concept of technology in the present dissertation is based on the Greek definition of technology, which represents artistic as well as instrumental construction.

Since the Enlightenment, the general understanding of technology has leaned toward the scientific component alone. According to the philosopher Martin Heidegger, the modern conception of technology has an instrumental and an anthropological definition: Technology is a means to an end, and technology is a human activity.[1]

Heidegger explains the Greek roots of technology with the word *Technikon*, which relates to *techné*. This calls attention to two things. One is the fact that *techné* is the name not only for the craftsman's activities and skills but also for the arts of the mind and the fine arts in ancient thinking. *Techné* relates to what it meant to 'bring forth', to *poiésis*; it is something poetic.[2] To Heidegger, techné never means a kind of practical performance and it never signifies the action of making. "*The word* techne *denotes rather a mode of knowing. To know means to have seen, in the widest sense of seeing, which means to apprehend what is present, as such. For Greek thought the nature of knowing consists in aletheia, that is, in the uncovering of beings.*"[3]

The author of the oldest theory of architecture known in Western civilization, the Roman architect Marcus Vitruvius Pollio (ca. 80-70-15 BC), made the distinction between *"the thing signified, and that which gives it its significance. That which is signified is the subject of which we may be speaking; and that which gives significance is a demonstration on scientific principles."*[4]

The Italian architect and architectural theorist Marco Frascari (born 1930) refers to the double-faced role of technology to unify the tangible and the intangible of architecture. The rational aspect of technology *logos of techné*,[5] the scientific construction of the representation of technology. Frascari refers to the mental and reflective representation of technology as the *techné of logos*, the construing of the representation of technology.

This understanding of technology, made up of two components. offers a simultaneous reading of mental and reflective aspects, *construings*, and of manual and operative aspects, *constructions* of the experimental data set.

In practice, symbolic and literal aspects of technology overlap in architecture. As argued by the Scottish architect and scholar Alan Colquhoun, this overlap is caused by the discrepancy between the logic of forms on a metaphorical level that is not necessarily the same as the one that comes into play in construction.[6] Quite fittingly for the focus on the dual-sided aspects of technology in *textile* concrete construction, Colquhoun illustrates his argument by pointing to Le Corbusier's use of the curtain wall, which features profiled and proportioned glazing bars to preserve the integrity of the plane and to create the feeling of a tight skin stretched over the entire surface of the building.[7]

1 Heidegger, Martin. "The Question Concerning Technology", p. 312

2 Ibid.318

3 Martin Heidegger, "The Origin of the Work of Art",184

4 Vitruvius, Pollo. *The Ten Books on Architecture.*, book I, ch 1.The Education of the Architect

5 Marco Frascari, "The Tell-the-Tale Detail", 500.

6 Alan Colquhoun, "Symbolic and Literal Aspects of Technology," in *Rethinking Technology: a Reader in Architectural Theory*, ed. William W. Braham, Jonathan A. Hale, and John Stanislav Sadar, Org. 1962. (London: Routledge, 2007), 267.

7 Colquhoun, "Symbolic and Literal Aspects of Technology".

8 Gevork Hartoonian, *Ontology of Construction: On Nihilism of Technology and Theories of Modern Architecture* (Cambridge University Press, 1994), 24. Hartoonian summarizes this as Semper's motto on the tectonic.

9 James Strike, *Construction into Design: The Influence of New Methods of Construction Architectural Design, 1690-1990* (Architectural Press, 1991), 41. Marked by the Great Exhibition in London in 1851

10 Hartoonian, *Ontology of Construction*, 24.

11 Mari Hvattum, *Gottfried Semper and the Problem of Historicism* (Cambridge University Press, 2004), 9.

12 Ibid.

13 Strike, *Construction into Design*, 41–7. Chrystal Palace was a temporary structure designed by the English gardener and architect Joseph Paxton. The Chrystal Palace was the largest glass building in the world, it was cheaper and faster built than other buildings at that size, and was in itself a demonstration of British technology.

14 Gottfried Semper, "Science, Industry and Art" (org. Germ. 1852), in The Four Elements of Architecture and Other Writings, (Cambridge: Cambridge University Press, 2010).

15 Ibid., 138.

16 Wolfgang Herrmann, Gottfried Semper : in search of architecture (Cambridge Mass.: The MIT Press, 1984), xi. In his foreword to Hermann's book the Swiss art historian Adolf Max Vogt suggest that Gottfried Semper would have been pleased with the analogy separating structure from skin by Paxton in a 1852 speech.

17 Adolf Max Vogt finds no evidence that neither Paxton nor Semper did noticed this connection that is so clear today. Semper did not consider Paxton work to belong in the category of architecture.Ibid., xiv.

18 Gottfried Semper, *Die Vier Elemente der Baukunst* (Vieweg, 1851). Translated to *The Four Elements of Architecture and Other Writings* (Cambridge University Press, 1989).

19 Die Holzarbeiten um das Dach und dessen Zubehör Semper, *Die Vier Elemente der Baukunst, 56.*

THE CONCEPT OF TECTONICS

"*How to change old forms, consecrated by necessity and tradition, according to our new means of fabrication.*"[8] This question frames the preoccupation with art-historical, almost anthropological search for the origins of architecture by the German architect and theorist Gottfried Semper (1803-1879). At the onset of the Industrial revolution[9] Semper sees architectural production in relation to techniques developed in other industries.[10]

At the onset of the industrial revolution architects called on the aesthetic paradigm of historicism and looked backwards, despite the concomitant explosive development of new materials and industrial techniques through industrialization. Gottfried Semper was positioned ambiguously here between historicism and modernism, idealism and materialism[11] and his theoretical work anticipated dichotomies that continue to haunt architectural discourse throughout the twentieth century.[12]

The industrialized techniques used for the construction of the Crystal Palace,[13] based on glass and steel, came to represent the a new architectural language and reflected underlying changes in modes of construction around the time of the Great Exhibition in London in 1851.

Based on his visit to the Great Exhibition Semper writes the 1852 essay on Science, Industry and Art[14] *(Wissenschaft, Industrie und Kunst)*. Here he examines the impact of industrialization upon the entire field of art and architecture.

"*[T]he restraint shown in the treatment of the difficult material – their whole demeanor indicates a beauty of style that to us, who now can cut the hardest stone like cheese and bread, lacks necessity. How should we treat granite now?*"[15]

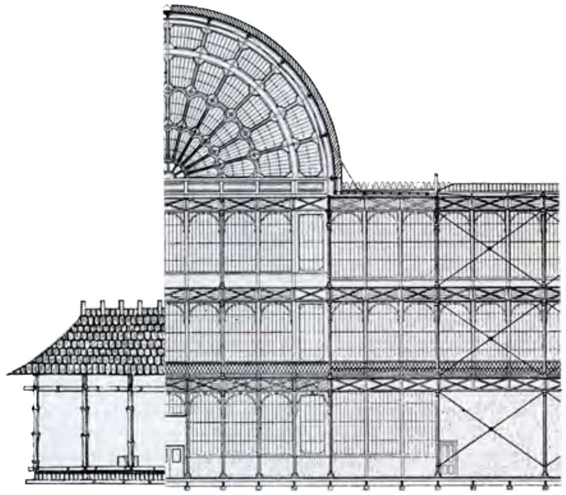
According to Semper, the foundation for a new concept of style must be based on the new methods and techniques combined with new tools and machines, rather than on the materials themselves.

The British architect Joseph Paxton had designed the exhibition hall based on his experience from using industrialized processes in building the first green houses. He explained the structural principle of the Crystal Palace by comparing the support structure to a table and the glass skin as a tablecloth. The improvement of the 'tablecloth' led to the possibility of the "table's being greatly varied to suit changing conditions and changing uses."[16]

The primal form for the structural principle of table and tablecloth of the Crystal Palace was exhibited within its own structure, namely as the 'Caribbean hut', which would influence the theories of Gottfried Semper.[17] In the essay *Die Vier Elemente der Baukunst*[18] Semper had identified four basic elements of architecture, ceramics, brick masonry, "*timberwork around the roof,*"[19] and the art of weaving.

Semper finds the Caribbean hut[20] to confirm this four-motive theory of architecture in their pure and most original form consisting of the hearth, the platform, the roof and the light wall. : *"the hearth as the center, raised earth as a terrace surrounded by posts, the column-supported roof, and the mat enclosure as a spatial termination or wall.*[21]

Gottfried Semper presents the argument that the distinction between textile as the space-defining element and the load-bearing structure of tents in early nomadic cultures makes textile



Wall and structure, primitive and modern. The Caribbean hut as represented in the Great Exhibition of 1851 compared with Paxton's Chrystal Palace, which housed the exhibition. (Reprod. from Hermann, 1984)

20 Herrmann, *Gottfried Semper,* 45–48. Semper lived in London at the time of the Exhibition and worked in the Chrystal Palace for five weeks doing interior design.

21 Gottfried Semper, *Style in the Technical and Tectonic Arts; or, Practical Aesthetics: A Handbook for Technicians, Artists, and Friends of the Arts.* (org. Germ. 1860/2004), 665–666. Described under the heading the Primitive Hut

22 Semper, *The Four Elements of Architecture and Other Writings.*

23 The most famous example and the basis for the principle for dressing *(Bekleidung)* is the relationship of two German words for walls. The loadbearing wall, *Mauer* is in German separated from the light wall, wand, which furthermore is associated with clothing, gewand. Semper, Style, 248.

24 Ibid.

25 Ibid.

26 Published in its first edition in 1844

27 Kenneth Frampton, "Towards a Critical Regionalism - Six Points *for an Architecture of Resistance", in Postmodern Culture, ed. Hal Foster (Pluto Press, 1985), 96.*

28 Karl Bötticher*, Die Tektonik der Hellenen. 2 vols.* (Pottsdam, 1842), 3. Cited in Herrmann*, Gottfried Semper*, 151.

29 the author Wolfgang Herrmann has studied the influence of Karl Bötticher's Die Tektonik der Hellenen on the work of Gottfried Semper. The term tectonics only starts to appear in manuscripts and notes for early versions of Der Stil written after he reads Die Tektonik in 1852 Ibid., 139–152.

a primordial element of architecture.[22] Semper backs this claim of a separation of the structure with the spatial enclosure with the material transformation from early textile partitions in nomadic tensile structures to the woven, spatial enclosure of the Caribbean hut. These woven infill walls are distinctly different from the tectonics of the frame, and the stereotomy of the hearth. Semper uses etymology and linguistic hierarchies to prove similar structural hierarchies in the origins of architecture. The basis for Semper's concept of dressing *(Bekleidung)* is thus the relationship of two German words for walls. The loadbearing wall, *Mauer* is in German separated from the light wall, *wand,* which furthermore is associated with clothing, *gewand.*[23]

Semper argues that *"the spoken language assists the early history of the arts by clarifying the symbols of the formal language in their primitive manifestation"*[24] and further links the German word *Decke* (cover, ceiling) with its textile origin.[25]

In the treatise Die Tektonik Der Hellenen[26] published in 1852, the German architect and art historian Karl Bötticher (1806-89) introduces the concepts of the *Kernform* (core- or kernel-form) or and the *Kunstform* (art-form) between the nucleus of construction methods and the decorative cladding of the same elements.[27] Furthermore he made a definition of tectonic as *"any activity having to do with building and furnishing."*[28] In Bötticher's use of the tectonic Semper found a significant general term that he further developed. In an early manuscript[29] for Der Stil in Den Technischen Und Tektonischen Künsten[30] Semper widens Bötticher's definition: *"Tectonics deals with the product of human artistic skill, not with its utilitarian aspect but solely with that part that reveals a conscious attempt by the artisan to express cosmic laws and cosmic order when molding the material."*[31] However, in Der Stil published in 1860, Semper narrows the term and confines the use of tectonic to the technical art of carpentry and its relation to architecture.[32]

Also the concepts of *Kernform* and *Kunstform* are adopted in Semper's theories.[33]

The focus in Der Stil upon locating the origins of art in order to lay the foundation for a science of architecture is characteristic of the eighteenth century's near obsession with origins, pursued in every dicipline.[34] Semper's interest in classifying and teaching the constituting factors that condition form thus ran parallel to contemporary establishing of a biological paradigm. Semper's categorization can be paralleled to work by the French biologist and zoologist Georges Cuvier (1769-1832). Cuvier's taxonomic system was new in *what* was being compared. He compared functions rather than form and defined an animal by relations and interactions between organs and not their individual formal properties.[35] This combination of function and form seem to be relations that Semper uses as well in order to make distinct the properties of materials and techniques.[36]

The inspiration from biology can be traced in the central concept of Material Metamorphosis *(Stoffwechsel)* developed by Semper.[37] This architectural theory of change describes an opinion that material was subject to the same evolutionary process as other artistic phenomenon.[38] When technological change from one material to another take place, some motifs, though modified, are also transferred, a process that has started at the very beginning and still continues.[39]

30 Gottfried Semper, *Der Stil in Den Technischen Und Tektonischen Künsten: Bd. Die Textile Kunst Für Sich Betrachtet Und in Beziehung Zur Baukunst,* Reproduction of original. (Frankfurt: Verlag für Kunst und Wissenschaft, (reprod. by Nabu Press), 1860). Translated to Style in the Technical and Tectonic Arts; or, Practical Aesthetics- Semper, Style.

31 Manuscript cited by Herrmann, *Gottfried Semper,* 151. Hartoonian, *Ontology of Construction, 23.*Gework Hartoonian has cited Semper in the same quote to express Semper's view on the tectonic without mentioning the unpublished source. It seems however, that this definition is close to the use of the tectonic by Frampton cited in the introduction of the present dissertation, which incorporates the notions of techne and poesis.

32 Semper introduces the formal language of Tectonics as "the art of assembling stiff plan-like elements into a rigid system." In the following short excerpt Semper generalizes the tasks of tectonics as "1. the frame with its corresponding *filling;* 2. the *lattice*, a complicated frame; 3. the *supports;* and 4. *structure*, an integration of the supports with the frame." Semper, Style, afs. 131.

33 In the essay Montage, Recoding the Tectonic Gework Hartoonian discuss the significance given by Semper to inside-outside formulated as the *Kernform and Kunstform.* The *Kernform* in architecture was the hearth; "in fact, the whole of Western architecture exhibits only ifferent tectonic forms of the Asiatic enclosed court architecture." Hartoonian, *Ontology of Construction,* 22.

34 Hvattum, *Gottfried Semper and the Problem of Historicism,* 30.

35 Ibid., 125.

36 Stoffwechsel is the German word for transposition, "material transformation" in English. This was the word used by Semper's friend Moleschott to describe metabolism in plants and animals.

37 "When an artistic motive undergoes any kind of material treatment, its original type will be modified; (...) The type is no longer in its primary stage of development but has undergone a more or less pronounced metamorphosis. If the motive undergoes a new change of material *[Stoffwechsel]* (...) the resulting new form will be a composite, one that expresses the primeval type and all the stages preceding its latest form.Semper, *Style,* 250.

38 Herrmann, *Gottfried Semper,* 149.

39 Ibid. This is also a reason for Semper's enthusiasm for the Caribean hut – it is not a theoretical model but "a highly realistic example of a wooden structure taken from ethnology" Semper, *Style*, 666.

40 Semper designed the building for the new polytechnical school in Zürich (1853–1864), known today as ETH Zürich, and became the first Professor of Architecture there in 1855.

41 Founded in 1978. The Structural correspondence with Semper's *Four elements of architecture* can be seen in The Stone House, Tavole (1994). Another Semperian concept is seen in the separation of the *Mauer* and the *Ge-wand* in the transparent ornamented façade of the Ricola-Europe warehouse (1992-93). as described in- Carrie Aasman, "Ornament and Motion: Science and Art in Gottfried Semper's Theory of Adornment", in *Herzog & de Meuron: Natural History,* ed. Philip Ursprung (Springer, 2005), 385-97.

Gottfried Semper designed the buildings for the ETH Zürich[40] and was also appointed the first Professor of Architecture. Semper's theories still inform architects trained at the university, for example the founders of the Swiss architectural office Herzog de Meuron.[41] The architects are famous for their use of exposed concrete as dressing and as sculptural monolith.[42] This focus on tectonic elements of construction based on a Semperian legacy at the ETH,[43] and especially the interpretation of the concept of dressing[44] may be one reason for the position of work by the architectural practice as challenging the boundaries between art and architecture. [45]

Structure, Construction, Tectonics

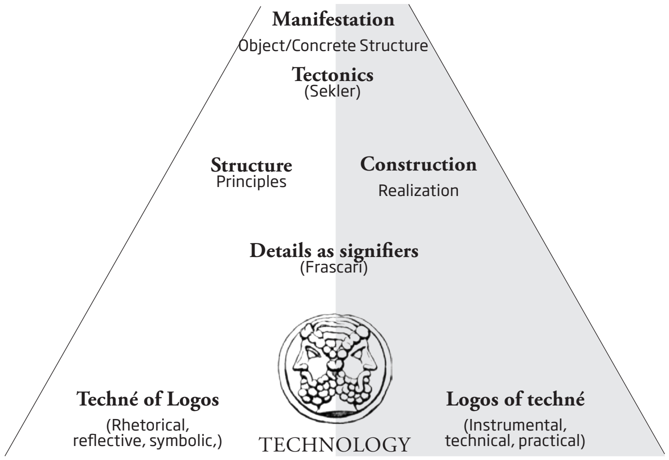
In his essay Structure, Construction, Tectonics[46] the American architect and historian Eduard Sekler looks at the relation between the closely linked yet distinct notions of structure and construction in architecture.[47] Sekler introduces the development of the concept of tectonic and highlights the introduction of the mental concept of empathy *(Einfühlung)* in the psychology of making to revitalize a Vitruvian focus on the direct relation between man and the forms of architecture. [48] Through the mental emphasis the tectonic is developed as an universal artistic activity of expression through 'making visible'[49]

In relation to architecture, Sekler draws a distinction between structure, which he defines as including the overall principles, and construction, which he defines as the careful execution of those principles by means of distinct materials, processes and techniques.
Sekler defines the tectonic relevance as that which cannot be explained by methods of descriptions of concepts and process alone.

"When a structural concept has found its implementation through construction, the visual result will affect us through certain expressive qualities which clearly have something to do with the play of forces and corresponding arrangement of parts in the building, yet cannot be described in terms of construction and structure alone. For these qualities, which are expressive of a relation of form to force, the term tectonic should be reserved."[50]

He argues that the resulting manifestation may be evaluated in response to either of these concepts, yet the whole must be considered as more than either structure or construction. The term *tectonics* is used here as the expressed quality and the clarity of the constructed, structural principle.

The dissertation applies Sekler's model for tectonics and specify it to concrete. It will thus be necessary to consider a set of structural principles within the structural principle of the constructed edifice of object, namely the structural formwork principles applied in constructing the mold.



Above: Diagram of conceptual elements in the dissertation

42 Herzog & de Meuron have, for example, expressed used concrete as dressing (Bekleidung) of the facades for the library for of the Technical University in Eberswalde, (1997-99), and as a sculptural monolithic for the Tenerife Arts Space (1999-2008).

43 Andrea Deplazes, ed., *Constructing Architecture - Materials Processes Structures, a Handbook*, 2 nd ed. (Basel: Birkhäuser, 2005/2010).

44 Examples HdM – 'woven' facades? Printed facades?

45 Philip Ursprung, ed., Herzog & de Meuron: *Natural History* (Springer, 2005).

46 Sekler, Eduard, "Structure, Construction, Tectonics", in *Structure in Art and Science*, ed. Gyorgy Kepes (George Braziller, 1965), 89-95.

47 Ibid.

48 Ibid., 91. Vitruvius, Book IV, Chaptcr I writes" *the Doric column began to furnish the proportion of a man's body, its strenght and grace*"

49 The artist Paul Klee cited in Ibid., 92. The concept appears closely connected to Heidegger's 'Bringing forth'

50 Ibid., 89.

CONCRETE AS MATERIAL AND PROCESS

Architectural form typologies for concrete structures can be categorized as a structural framework, a shell or a sculptural solid. These three categories overlap in procedures of construction – the framed structures and shells may be produced on site – or conceived as an overall structure broken down and produced by smaller units of prefabricated elements.

Whereas the shell can be considered as tensile, a surface 'tensioned' like a tent, and the structurally framing concrete is understood based on the tectonics of rigid members, the sculptural solid is fundamentally different. The category of a sculptural solid is bound to procedures of casting in situ and the architectural archetype of the cave.[51] The sculptural solid is defined through an understanding of the plasticity of concrete, the quality of being easily shaped or molded. In this way, concrete structures conceived as a monolithic structure can be defined as architectural concrete because the exploration of the material has formal and spatial agendas that may precede a structural purpose.

The division above represents positions of tectonic discourse in which the formal expression of concrete architecture has been associated with an architectural archetype. For example the oeuvre of Le Corbusier has been analyzed through the resemblance of his buildings to the 'tent' or the 'cave' or their use of tectonic principles derived from the assembly of rigid elements.[52]

Architectural concrete and molds

Concrete must be understood in relation to the mold that gives it shape.[53] The words mold, formwork, shuttering, and falsework can all be defined as temporary-to-permanent structure used to contain or support concrete and thus mold it into the required dimensions until it is able to support itself.

Since the concrete mold is basically a constructed space to be filled with concrete, the general development of a theory of formwork tectonics is based on the notions and principles for all possible materials to create such formwork structures, including the tectonic possibilities for linear boards and flat surfaces, principles of creating the mold by removing material from a block, or creating an interior space by adding or piling material to become falsework.

Detailed technical aspects of the concrete mix and the reinforcement principles are not in focus in the present dissertation, and what fills the formwork is roughly categorized as the concrete mix and reinforcement.

The definition of the architectural understanding of forming and molding reinforced concrete structures can be summarized in a definition of 'architectural concrete' that distinguishes between what is inside the form, and what defines the form.

An understanding of concrete as an architectural material is illustrated on the next page and conceptualized as a handful of parameters that includes the materials that fill the mold as well as the materials and surfaces that define the mold. Such a model allows qualities or properties of each of the 'fingers' to be considered as a generator of sculptural form, surface tactility, and efficiency in relation to structure or construction.

51 For examples in readings of work by Le Corbusier Kenneth Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture* (The MIT Press, 2001), 343–46. In 1803 Quatremère de Quincy posited a triadic origin to all construction: the tent, the cave, and the hut. Ibid., 395.

52 In this way, the structural frame relates to the notion of the tectonic frame, the shell relates to the tent typology, and the monolith relates to the cave. Ibid., 343–46.

53 Peter Collins, *Concrete,* xxxv. The book by the British architect and architectural historian Peter Collins (1920-81) is a combination of a monograph on the architect Auguste Perret, and the history of concrete told through mainly technical events.

54 Semper, *Style,* 109–10. The categorization of raw materials and procedures are listed in summary as 1. Pliable and resistant to tearing (textiles); 2. Soft, plastic (ceramics); 3. Stick-shaped (tectonics of carpentry); and 4. Densely aggregated and of high compressive strength (stereotomy of masonry).

55 1. Light facade dressing (textile), 2. sculptural/moldable monolith (ceramics), 3. tectonics of concrete elements, and 4. stereotomy of concrete blocks

56 it is difficult the separate the concept of molding from the Semperian category of *ceramics* but the relation between the mold and the molded material forms parts of all of the categories.

57 Sekler, Eduard, "Structure, Construction, Tectonics".

58 Structural formwork principles and their tectonics vary, depending on the material properties of the formwork elements.

59 Peter Schjeldahl, "Scott Burton: The Concrete Work" (1992) in *Columns & Catalogues* (Great Barrington MA: The Figures, 1994), 196–98.

60 Adrian Forty, "A Material Without a History", in Liquid stone : new architecture in concrete, eds. Jean-Louis Cohen and G.M. Moeller (New York: Princeton Architectural Press, 2006), 35.

In Semper's Style he emphasizes that his classification system should be understood widely and stylistic combinations of his dressing principle with tectonics emerges in lattice construction when tectonic stick-like elements provide the material and textiles give it shape. [54] Contemporary concrete architecture can thus be developed through all procedures within a Semperian framework.[55]

The general focus in this dissertation deals with *molding* and the relation between that which is the *molded* and the *mold*.[56] that can elaborate on a didactic relationship between Structure, Construction and Tectonics[57] by the American architect and scholar Eduard Sekler. In the specific focus on fabric-formed concrete in the dissertation the expressed clarity of structural formwork principles is discussed through their stereogeneous consequence. This is the direct formal consequence of the principles and details of the formwork.[58]

Concrete-ness

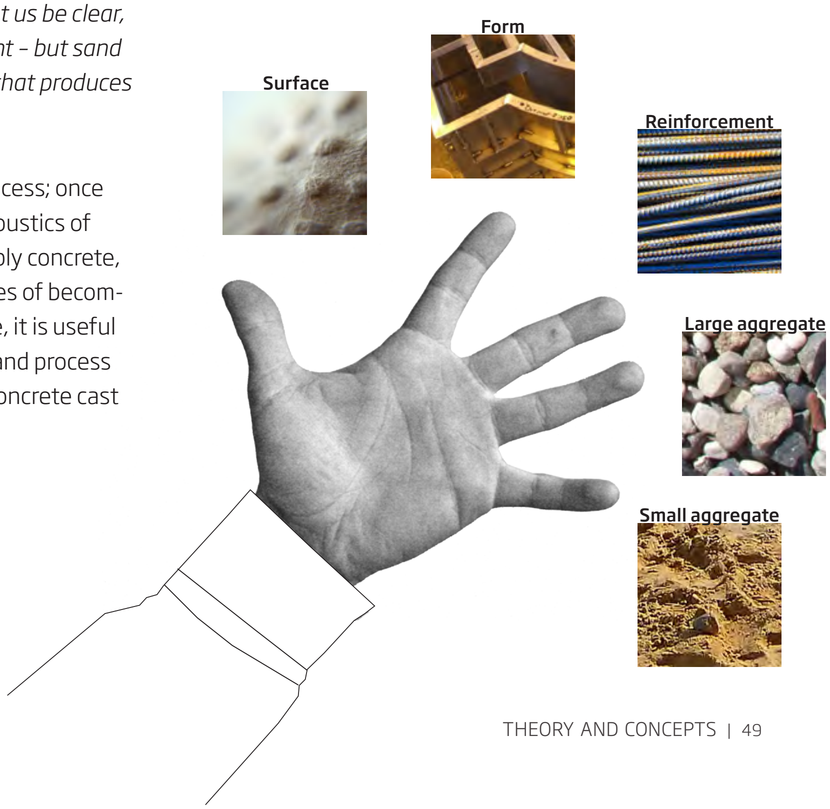
An essay by the American art critic and poet Peter Schjeldahl describes the intrinsic dichotomy between fluid and solid characteristics of concrete.

"Concrete is the most careless, promiscuous stuff until it is committed, when it becomes fanatically adamant. Liquid rock, concrete is born under a sign of paradox and does not care [...] Concrete hardens in the shape of whatever container received its flow, its momentary sensual abandon in thoughtless submission to half-loved gravity. Once it has set, what a difference! Concrete becomes adamant, fanatical, a Puritan, a rock, Robespierre – the divinity! – of the shape it comprises, be the shape a glopped heap on the ground or a concert hall, ridiculous or sublime." [59]

This critique of the 'promiscuous' fresh concrete and the 'fanatical' cured concrete is simultaneously a critique of the maker of mold. Builders and scientist consider concrete as a process, an opinion, which is shared by the British architectural historian Adrian Forty.

"The incertainty that is such a feature of the aesthetics of concrete undoubtedly has something to do with its common, but mistaken, designation as a material. Concrete, let us be clear, is not a material, it is a process: concrete is made from sand and gravel and cement – but sand and gravel and cement do not make concrete; it is the ingredient of human labor that produces concrete."[60]

As an architectural material, however, concrete cannot be seen merely as a process; once cured concrete structures are solid and durable. The tactility, temperature and acoustics of concrete architectural spaces can be experienced with all senses. Concrete is simply concrete, a solid material or a structure, and at the same time the manifestation of processes of becoming. In order to discuss the architectural potentials of fabric formwork for concrete, it is useful to define further this concept of the duality of architectural concrete as material and process since the formwork-tectonic principles and procedures are especially present in concrete cast in a flexible mold.



Stereogeneity

Schjeldahl's use of the word *concrete-ness*[61] is descriptive of the general conditions of liquid and solid concrete as a material for casting. However the term lacks rhetorical nuances; using concrete-ness would be similar to using a term like *clay-ness* for masonry architecture. Schjeldahl emphasizes this lack of qualitative aspects of his view on concrete when he describes his confrontation and fascination with concrete sculptures by the artist Scott Burton:

My eye and mind leap to the object to grasp it, then my grasp comes away, slipping from the object. My grasp brings away abstract qualities: purity of intention, ideality of conception, perfection of follow-through. It is a wonder to me in that moment that the concreteness left behind doesn't literally crumble.[62]

To Schjeldahl the qualities of the concrete sculpture have little to do with concrete and everything to do with the craftsmanship and the artist's eye. In this way Schjeldahl would agree with Forty who finds it difficult to apply to concrete "*Martin Heidegger's notion that a work of architecture is the 'bringing forth' of the immanent properties of stone and metal that lie dormant in the ground […] what, if anything, is 'brought forth' in concrete is human invention and skill.*"[63]

With kind assistance from the Greek author Iosif Alygizakis this dissertation presents a coined a word, which attempts to embrace the duality of, on the one hand the experienced, sensed qualities of a cured concrete structure as material and, on the other hand, those almost metaphysical traces of becoming that may be the most poetic feature of concrete. The term *stereogeneity* comes from the Greek word *stereogenés*. It consists of two words: *stereo*, solid, and *genés*, derived from *ginomai*, the procedure of becoming or *to begin to be*.[64] Cured concrete then is stereogeneous; it is solid but, as the word indicates, has become solid through a number of processes beginning with a liquid state.

These procedures of becoming include processes of chemistry and statics; the chemical processes within the concrete mix when cement reacts to water and the formwork statics as the form is filled with concrete. Both are the results of human intervention: the former through the design of the concrete mix, and the latter through the design and construction of the formwork tectonics.

Concrete is nothing without its process – yet it is definitely something during its use, something more than merely a structure that defines a space. The further unfolding of stereogeneity will attempt to establish a holistic view of concrete as both process and material and suggest that a stereogeneous approach to construction by working with instrumental and rhetorical representation of technology, offers a way of revealing a poetics of concrete.

Objects

In a series of essays written in the late 1960s and early 1970s the Danish sculptor and later Professor at the Royal Danish Academy of Fine Arts Schools Willy Ørskov (1920-90) developed an epistemology of sculptural art named Retrospective Object Theory.[65] The object theory revolved around the development of a new conceptual art scene at the time and basically

61 Peter Scheldahl footnote

62 Schjeldahl, *Columns & Catalogues*.

63 Forty, "A Material Without a History", 35.

64 As formulated by Alygizakis at a meeting about the term. See the *Terminology* or the *introduction and Researh Questions* for the suggested formal definition of Stereogeneity

65 In his *retrospective object theory* in the "Objects – process and condition" (Org. Danish: *"Objektbegrebet I bagudrettet perspektiv"* i*n "*Objekterne – proces og tilstand"),'Objekterne' (1972) in Willy Ørskov, *Samlet : Aflæsning af objekter, Objekterne, Den åbne Skulptur,* Antology of writings. (Borgen, 1999), 7.

describes artistic objects as relations of becoming between *process* and *conditions* over time, and as interpretations between *function* and *form.* (the figure, right)

Where as Ørskov finds science to be a postulate he defines art as that we accept as being art and continues, "*Art is uninteresting without proof but it is different for the arts than for science*."[66]

Ørskov discuss the concept of condition using his own pneumatic sculpture as example. If the object's condition is not inflated it is not a sculpture unless the inflation of the sculpture in fact is part of the art historical situation.[67] For the present architectural research situation, experimental data represents a series of conditions that are subject to hermeneutical interest.

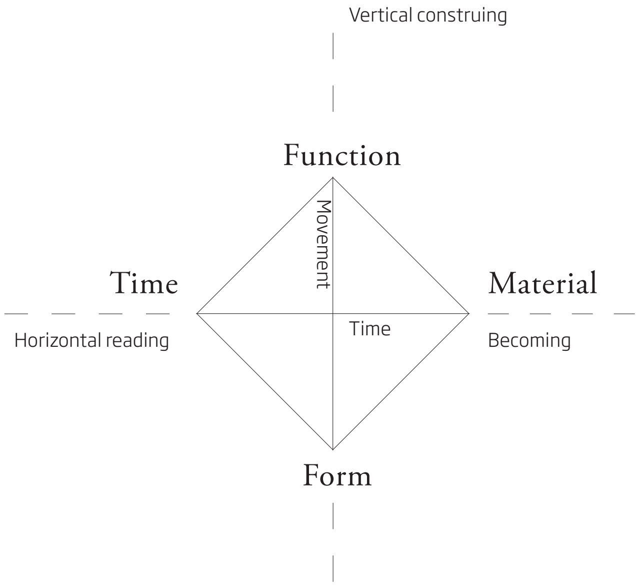
The formation of these initial ideas, processes and stereogeneity can be defined as conditions in the development or becoming of architectural concrete objects. The experimental data is understood in several ways.

- *Documentation of a series of conditions between rhetorical aspects of construings of the concrete and the formwork structure,*
- *Technical aspects in regard to the techniques and materials used for constructing it, a nd*
- *The resulting concrete structure, with its stereogeneity presence.*

To look at the stereogeneous concept in relation to this model, two applications of the concept of tectonic are present in the thesis. One application deals with the relation between parts and whole in the 'art of joining' in the fabric formwork structures. This concept of formwork tectonics seems pragmatic in the practice of making. This definition of tectonic is however also close to the use in Danish of the word structure, derived from Latin *struere*, to pile up. The German architect Mies van der Rohe (1886 – 1969) defined structure in architecture as a philosophical concept: 'The whole, from top to bottom, to the last detail, with the same ideas.'* He saw structural order as a condition where 'form becomes a consequence of structure and not the reason for the construction.' The other use of the tectonic in the dissertation is present in the analytical studies of fabric formed concrete objects. Here, stereogeneity is used for concrete as specific elaboration of Sekler's model of structure, construction, tectonics.**

Concrete structures can be described in terms of their measurable performance within the parameters of structural engineering, or as material and spatial phenomena. The Finnish architect and theorist Juhani Pallasmaa thus describes how tactility can be experienced with the sense of touch where "the skin reads the texture, weight, density and temperature of matter."[68] To study traces of formwork tectonics in the concrete object, however, means working as a stereogeneous archeologist, an endeavor that is preconditioned by in-depth knowledge of the material principles and notions of formwork tectonics.

It is not in all concrete objects in which traces of becoming tell the tale of its formwork materials. This may lead to points where it is difficult to decipher the becoming, the geneity of the concrete solid. In such a situation, stereogeneity is left as vague traces of conditions between structural principles, and processes and materials of construction.



From: Ørskov, Objekterne - proces og tilstand

66 Willy Ørskov, "Aflæsning af Objekter og Andre Essays", in Samlet : Aflæsning af objekter, Objekterne, Den åbne Skulptur, Antology of writings. (Borgen, 1999), 63. Translated by the author: "*[M]ens videnskab jo er et postulat, som kan ledes i bevis, er kunst i største almindelighed; det vi godtager som værende kunst – det som vi lader os sanseligt medrykke (medrive) af*."

67 Willy Ørskov, "Objekterne - Proces og Tilstand: forslag til en objektteori", in *Samlet*, 92–98.

* Ludwig Mies van der Rohe and Peter Carter, *Mies van der Rohe at Work*, 9.

** The linkage is thus close between the Danish use of structure and the use by the Germanic roots of the German van der Rohe and the Austrian Sekler.

68 Juhani Pallasmaa in Juhani Pallasmaa, *The Eyes of the Skin: Architecture and the Senses*, 2. ed. (Academy Press, 2005), 56.

TEXTILE AS SURFACE, STRUCTURE, METAPHOR

In order to make a deeper investigation of the formwork-tectonics for fabric formwork, here follows an introduction to textiles in the construction of architecture. Textiles are understood as surface, as structure as well as textiles used as metaphor.

The term textile originally describes a specific mode of fabrication, to weave; from Latin: *textilis*, woven, fabric, cloth.[69]

Today the word textile is applied generally to any one of the following:

1. Staple fibers and filaments suitable for conversion to or use as yarns, or for the preparation of woven, knit, or nonwoven fabrics.
2. Yarns made from natural or manufactured fibers.
3. Fabrics and other manufactured products made from fibers as defined above and from yarns.
4. Garments and other articles fabricated from fibers, yarns, or fabrics when the products retain the characteristic flexibility and drape of the original fabrics.[70]

The diagram shows fibers divided between natural and man-made fibers. The selected fibers are suitable as fiber and textile reinforcement for concrete.[71]

```
Fibers
├── Natural Fibers
│   ├── Mineral Fibers
│   │   ├ Basalt
│   │   └ Asbestos
│   ├── Vegetable Fibers
│   └── Animal Fibers
├── Man-Made Fibers
│   ├── Inorganic Fibers
│   │   ├ Basalt
│   │   ├ Alkali Resistant Glas
│   │   └ Z-Glass
│   └── Synthetic Polymers
│       ├ Aramide
│       ├ Carbon
│       ├ Acrylic
│       ├ Polyethylene
│       └ Polypropylene
│         Polyvinylalcohol
├── Ceramic
└── Metal
```

Textiles are divided between natural and man-made fibers. The figure shows four groups of fibre material applicable as fiber reinforcement of concrete. (Brameshuber, *Report 36*, 12)

The word fabric is derived from: *fabrica*, workshop, and the French *fabriquer*, to manufacture, and describes a number of fabrications. The sense in English evolved via 'manufactured material' to 'textile.'[72]

Where textile is a general mode of construction, fabric is defined as a planar textile structure produced by interlacing yarns, fibers, or filaments.[73] In the thesis the two terms will be used about fabrics. Textile will however also be used for what is later defined, and referred to, as textile notions and textile tectonics.

For clarity, notions refer to rhetorical or symbolic aspects of textiles, while technical concepts and aspects will be described as *principles.* Behavior such as wrinkling and deflecting into catenary curves can be described as technical aspects but textile behavior and properties can also have values that cannot be defined as technical.

Textile origins in the construction of architecture

The understanding and use of textiles in architecture is an immense field of study, and in this context it will only be possible to scratch the surface of this topic. In architectural theory, since Vitruvius, weaving has been described as one of the original procedures of construction. Vitruvius describes the woven construction of two of the earliest constructions of shelters: a shelter woven of fresh 'greens', and a construction that is 'inspired by swallows': a composite that is mud-built upon a woven reinforcing structure.[74]

From its application in tents, the tensile structure is considered one of the original building types.[75]

69 "the definition of textile", www.d*ictionary.com,* u.d.(Accessed 10-1-2012).

70 Textile, Celanese Acetate, *Complete Textile Glossary,* 5. ed. (New York, USA: Celanese Acetate LLC, 2001).

71 Wolfgang Brameshuber, *Report 36: Textile Reinforced Concrete - State-of-the-Art Report of RILEM TC 201-TRC* (RILEM Publications, 2006), 11-12.

72 "definition of fabric", *Dictionary.com*, u.d.

73 Celanese Acetate, *Complete Textile Glossary*.

74 Pollo Vitruvius, *Vitruvius: the ten books on architecture* (Dover Publications, 1914), b. II-1, Dwelling.

75 Quatremère de Quincy's triadic origin to all construction: the tent, the cave, and the hut.

76 Mark Garcia, "Introduction, Architecture + Textile = Architextiles", in *Architextiles*, Architectural Design 76, No. 4. Chichester: Wiley, 2006, 5-11.

77 Hodge, Brooke, Patricia Mears, and Susan Sidlauskas. *Skin + Bones: Parallel Practices in Fashion and Architecture*. London: Thames & Hudson, 2006. The exhibition catalogue section about *Tectonic strategies* describes explorations of textile properties through draping and folding, and textile manufacturing principles through interpretations of weaving.

Textiles in contemporary architecture and construction

The term *Architextiles* has been proposed about a body of textile architectural projects as a hybrid term that combines 'architectures' and 'textiles,' ways of thinking and making. The increasing *architecturalization* of textiles and *textilization* of architecture cover, more simply put, architectural ways of thinking and doing in textile design and a textile way of thinking and doing in architecture.[76] This may be one reason for the recent popularity of the theories of Gottfried Semper. Semper's seminal theories about *Bekleidung* as the element that separates the building envelope from its structure are sometimes merged with Semper's structural principles of tectonics.[77] Semper relates tectonics to the rigidity of the frame and states that the main task of tectonics is to deal with the art of assembly in the relation between support and frame.[78]

Textile notions and properties are blurred when properties associated with constituting principles for stable structures (tectonics) are confused with the protecting or space-defining role of a surface (dressing).

The following categorization of textiles attempts to clarify the distinctions between textile as surface, structure, and ornament versus textile as pliable skin *and* rigid structure. The dual-sided view of technology introduced earlier as a concept that contains both rhetorical and technical aspects of representation[79] is reflected in this categorization.

Textile thinking refers to an existing notion of conceiving architectural spaces by a manipulation of pliable surfaces obtained by folds, pleats, cuts, hollows and wrapping. These procedures merge what was once considered as the separate elements of floor, wall and ceiling.[80] Theoretically, such textile thinking expands the decorative and space defining Semperian textile surfaces with a structural role that is made possible by new materials and techniques. The figures illustrate textile-structural relation: for the metaphorical use of skin of a building envelope, which is hung on a substructure, the literal use of coated, structural textiles in early aviation,[81] and in art. [82]

Textile Tectonics

In recent years, the development of materials and manufacturing methods has lead to a growing interest in textile principles in relation to structure and in forming an actual theory of *textile tectonics*.[83] The Dutch architect and Professor at Georgia Institute of Technology, Lars Spuybroek (1959) suggests *textile tectonics* as a theoretical category of textiles seen as structure to complement the more famous Semperian relationship between textiles and dressing. Semper only briefly mentions the construction of textiles[84] and textile architectural elements are changed into ornamental aspects.

"I want the textile to become tectonic itself. In that case the soft elements become rigid through collaboration, by teaming up, by weaving, bundling, interlacing, braiding, knitting or knotting, and through that convolution the whole becomes strong and rigid."[85]

Spuybroek argues for a theory of textile tectonics from the fact that textile techniques turn flexible fibers into stable structures.[86]

'Dressed' architecture, surface and structure are separated in Walt Disney Concert Hall, Los Angeles, by Frank O. Gehry, (Photo: Carol Highsmith). Right, construction of the substructure (photo: Grant Mudford).

Early aviation technology based on structural-textile relations.

The American artist Kendall Buster offers an artist's take on these textile/structural relations, exemplified here in large objects that expose the supporting structure through a delicate textile skin. *Fluent Traces*, permanent installation, Washington, DC. 2006 (image from kendallbuster.com)

Below are listed a few examples of technical textiles that achieve their specific performance through textile tectonics in aeronautics, reinforcement, and the construction of car parts.

- Textile structures have long been recognized as a smart reinforcement for applications in ranging from aircraft wings produced by Boeing Aircraft Co. in the 1920s to carbon-carbon nose cones produced by General Electric in the 1950s.[87]
- Recent developments in 3-D reinforcement for composites include textile techniques, such as braiding, stitching, warp knitting, weft knitting, and weaving.[88]
- A structural application of 3-D woven carbon fibers is a strong and lightweight component for the luxury car Lexus LFA. Parts made on a high-tech, laser-guided circular loom.[89]

The dual-sided technological view on textile

Elaborated textile structures[903] with different textile properties, performance, manufacture, and scale show new ways of construing and constructing the use of textiles in architecture. [914]

Center for Information Technology and Architecture (CITA)at RDAFASA[920] collaborates with textile manufacturers in architectural research and works with technology in both a rhetorical and technical sense.[931] The research practice at CITA is relevant to mention here because it combines the construction of textile, i.e. the pragmatic textile tectonics, with textile as a responsive but still metaphorical skin.The images on the next page illustrates how advanced technical aspects material fibers and textile manufacturing techniques for knitting are combined with a study of rhetorical properties identified by the authors as the composite, the bespoke, the complex formed, and the pliable key.[942]

The flexibility of textiles and their high tensile strength compared to their weight makes them an interesting and radical alternative to conventional formwork materials for casting concrete. Interesting because they are easy to handle and ship, and because they offer the potential of producing advanced geometries with flat sheets of fabric. Radical because the structural role of light textiles when casting heavy rigid structure reverses the relationship of the light and the heavy that was so seminally categorized by Semper. Another radical aspect is actually in line with Semper, who refers to the textile as the *Urtechnik*, the original technique in architecture and now, additionally, described by Spuybroek as a way of thinking architecture with techniques that operate on a material level. [95]

As the wider introduction to textiles in architecture and construction indicates, textiles might hold increased potentials for fabric formwork if the vocabulary for textile notions and principles can be expanded and qualified. Similarly, the reinforcement technologies grouped as *textile concrete*[96] may achieve wider architectural application or 'architecturalization' if textile notions in construction and concrete are explored and discussed.

Textile as metaphor has not been elaborated much here. In the following chapters about *Concrete and Concreting* textile as metaphor and principle will run as an underlying theme.

78 Semper introduces the formal language of Tectonics as "the art of assembling stiff plan-like elements into a rigid system." In the following short excerpt Semper generalizes the tasks of tectonics as "1. the *frame* with its corresponding *filling;* 2. the *lattice*, a complicated frame; 3. the *supports*; and 4. *structure*, an integration of the supports with the frame." Semper, *Style*, sec. 131.

79 i.e. *logos of techné* and *techné of logos*

80 Mette Ramsgaard Thomsen andToni Hicks, "To Knit a Wall, knit as matrix for composite materials for architecture", in *Smart Textiles, technology and design, International Scientific Conference, Proceedings*, bd. 2008 (presented at Smart Textiles, technology and design, International Scientific Conference, Borås, Sweden, 2008).

81 Early prototypes of light aviation devices consisting of tensioned membranes stretched over a slender reinforcing skeleton. The German Otto Lilienthal (1848-96) was known as the first aviator. Otto worked with his brother, Gustav Lilienthal, the inventor of the first patent for a fabric formwork principle."Otto-Lilienthal-Museum Anklam", u.d., www.lilienthal-museum.de/olma/egustav.htm.

82 Kendall Buster, u.d., www.kendallbuster.com

83 Lars Spuybroek, *Textile Tectonics: Research and Design* (NAi Publishers, 2011); Lars Spuybroek, *The Architecture of Variation - Research & Design* (Thames & Hudson, 2009); Matilda McQuaid, "Tectonics and Textiles", in *Architextiles*, ed. by Garcia, 98-101.

84 For example in the description of the Loop Stitch described as a system of knots [§53], "They carry the elements of their richest ornaments *in themselves* in their *construction.*" Semper, *Style*, §53. and the spatial, structural use of *lattice* [§136], which he categorizes as a *complicated frame* and initially describes as a light but flat, rigid system resembling a grid. Nevertheless, the *complicated* nature of the lattice is illustrated in drawings of the *Etruscan Couch* in which the seat is made by apparently tensile woven latticework across a rigid frame.

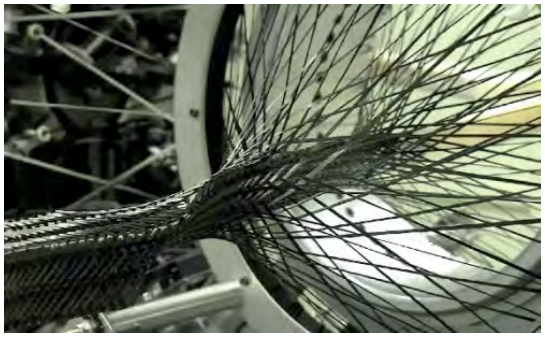
85 Maria Ludovica Tramontin, "Textile Tectonics, An Interview with Lars Spuybroek", in *Architextiles*, edited by Garcia.

86 Spuybroek, *Textile Tectonics*, 7.

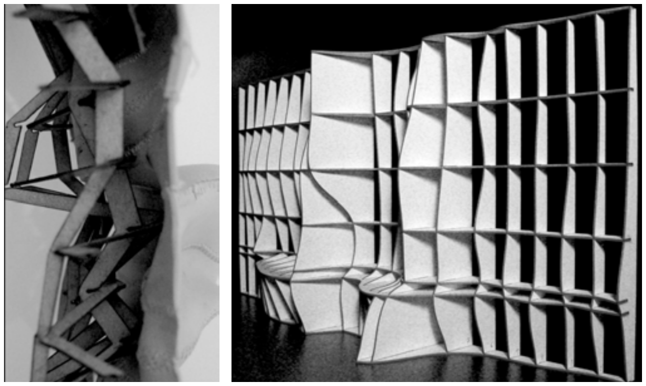
87 Writes Frank K. Ko from the Department of Materials Engineering, Drexel University, Philadelphia, PA, USA in the article"3-D textile reinforcement in composite materials" in *3-D textile reinforcements in composite materials* , edited by A Miravete (Cambridge, England: Woodhead Publishing Limited, 1999), 9.

88 Ibid., 5. Weaving is an interlacing formation technique, braiding intertwines, knitting interloops.
Kathryn Hatch, *Textile Science* (Minneapolis/Saint Paul: West Pub., 1993), 342. Weft knits are mostly characterized by the fact that each weft yarn lies more or less at right angles to the direction in which the fabric is produced; the yarns lie crosswise, where as warp knits are characterized by the fact that each warp yarn is more or less in line with the direction in which the fabric is produced; the yarns lie lengthwise.

89 See the link to a film of the weaving process in the blog post about the potentials of a 'woven architecture' Anne-Mette Manelius, "CONCRETELY: Weaving galore", Blog, *Concretely*, May 8, 2011, http://concretely.blogspot.com/2011/05/weaving-galore.html.



3d-loom weaving carbon fibers for structural car parts for the luxury car Lexus LFA.



Left: knitted scale model for developing concepts for thinking knit at architectural scale.
Right images: Physical models thinking relationship between wood substructures and textile skin. (Illustrations reproduced from Thomsen and Hicks)

90 Such as tensile textile principles shown in Tristan Simmonds, Martin Self, and Daniel Bosia, "Woven Surface and Form", in *Architextiles,* ed. Mark Garcia, Architectural Design 76, No. 4. (Chichester, 2006), 82-89; or the studies of textile principles forming *vertical* architectural structures, in Spuybroek, *Textile Tectonics.*

91 Philip Beesley and Sean Hanna, "A Transformed Architecture", in *Extreme Textiles: Designing for High Performance,* ed. Matilda McQuaid (Princeton Architectural Press, 2005), 182-213. Using a textile structure for a building manufactured on site was proposed for the Carbon Tower (2004) by Testa & Weiser

92 Directed by Professor Mette Ramsgaard Thomsen.

93 Besides the clearly addressed dual-sided aspects of technology, the project *Knitted Wall* includes aspects of textiles as structural skin, textile thinking, and textile interpretations. Thomsen and Hicks, "To Knit a Wall".

94 Ibid., 1–5. The focus on the relationship between the substructures and the development complex and 'smart technical textiles addresses a critique of the 'mono-functionality' of textile construction in the 1970s and 80s, which reduced the textile to rain and sun screen.

95 Tramontin, "Textile Tectonics, An Interview with Lars Spuybroek", 53.

96 The term has been used about concrete reinforcement since 1999 at the "Collaborative Research Center 532" based at RWTH Aachen University; see for example the summary of a prototype building project (2006-2010) "Summary of Results for the Project INSUSHELL" (Institut für Textiltechnik der RWTH Aachen University, u.d.), www.life-insushell.de/.html. (Accessed 20-10-2011)

3/ PRACTICAL INVESTIGATION

INTRODUCTION TO PRACTICAL INVESTIGATION

CONCRETE AND CONCRETING

TEXTILES IN CONSTRUCTION

FABRIC FORMWORK

INTRODUCTION TO PRACTICAL INVESTIGATION
Practical investigation into formwork tectonics and stereogeneity

Concrete and concreting
Stereogeneous construction
Textiles in construction
Fabric formwork

This section contains a series of chapters that spans between an overall introduction to the material concrete in regard to principles of construing and construction, and the specific formwork-tectonic materials, elements, and construction principles of fabric formwork.

Fabric Formwork is the pivotal formwork-tectonic topic of investigation in the empirical and analytical parts of the dissertation. The youth of the application of construction methods for fabric formwork for concrete means, however, that initial structural formwork principles[1] and construction procedures as well as the expressed methods of construction have yet to be combined to create architectural space and place in architectural concrete constructions. In order thus to locate architectural potentials for this method of construction for concrete, the section displays different paths of forming the framework for the study before the formwork method is introduced.

The first chapter, *Concrete and Concreting* is the largest part of this section. The chapter contains selected themes within the architectural field of concrete and concrete construction that especially highlights aspects which enhance the expression of concrete as a series of conditions during construction.

The concepts of formwork tectonics and stereogeneity are applied to selected architectural examples. Textile elements are emphasized and architectural examples illustrate ways of thinking in regard to the construing and construction of architectural concrete structures, forms, space, and surface and include aspects of formwork tectonics, that is to say the relation between materials, parts and the whole in formwork structures, the procedures and materials of construction.

The underlying range of textile thinking in the chapter provides a broad field of reference for the potentials within the scope of research, ranging between the symbolic notions of textile concrete and the instrumental principles of fabric formwork.

Then follows additional usage of *Textiles in Construction* to supplement the textile examples for concrete and the techniques already introduced in the Introduction chapter.

At the end of section comes the chapter about the development and construction principles for *Fabric Formwork*.

1 Structure as the linkages and relationships between parts and whole as defined in the Terminology

CONCRETE AND CONCRETING

Concrete and concreting

Stereogeneous construction

CONCRETE AND CONCRETING

This chapter investigates concrete in architectural constructions. The view on architectural concrete as a series of conditions between fluid and solid that was introduced at the beginning of the dissertation is applied. Following this thinking concrete architecture is then conceived as a process, a way of thinking and doing concrete, and as a material, the solid cured manifestation of the structural formwork principles and procedures of construction. Furthermorem the term material is understood as a conglomerate of idea, materials, and processes, that is to say a metaphor for what concrete architecture is *made of*.

This chapter is then an introduction to a view on architectural concrete as an evolution of molding walls from the caementum walls of Roman antiquity towards a complexity of concrete notions of fluidity in process and materiality.

Brief technical introduction

Concrete[1] is a mixture of binder, water and aggregate. Additions and admixtures can be added to these main ingredients. Admixtures may be in powder or liquid form and influence the properties of the fresh or hardened concrete. Concrete can be unreinforced or reinforced to suit the intended use – in the present dissertation concrete structures refer to reinforced concrete. Since concrete is high in compressive strength but weak in tension, steel, plastic, graphite or glass is incorporated in the form of bars, wires, mesh or fibers to resist tension by composite action.

The material can be classified as low, normal or high-density (or weight) concrete and mainly differentiated by its aggregates.[2]

The majority of applications are based on normal density concrete, which is designated by a density between 2000 and 2600 kg/m3.[3]

The most important property of concrete is its compressive strength. Grade classes divide the compressive strength between normal, and high strength. Today, concrete with compressive strengths above 50MPa [4] is considered high strength concrete[5]

VIEWS ON CONCRETE

Practitioners of architectural technology consider concrete differently, depending on the focus in their corner of the science and art of construction. A rough definition of the interests of concrete construction workers or 'concreters', structural and chemical engineers, and architects, respectively, establishes concrete as process, performance and matter.

Concreters' Concrete

Concreters, defined as the workers and engineers on a building site, consider concrete structures as the product when they *produce concrete*. These contractors refer to the workability and strength of concrete. The slump refers to the consistency of the concrete mix and is an indication of the workability of concrete, how easily it will flow into the intricate corners of the formwork, and how thin or thick it is. The strength tends to indicate how fast the concrete begins to set. When concrete loses its viscosity the hydrostatic pressure within the formwork drops. The strength or the set time thus indicates the speed of filling tall formwork.

1 Based on Friedbert Kind-Barkauskas et al., *Concrete Construction Manual* (Basel: Birkhäuser, 2002), 47–51.

2 The weight is based on the oven-dry density of the mix materials

3 Kind-Barkauskas et al., *Concrete Construction Manual*, 50–51. Low-density concrete (lightweight) concrete has a density up to 2000 kg/kg/m3. Used aggregates include pumice, expanded clay, and expanded shale. High-density (heavy) concrete, exceeding 2600 kg/m3, has applications that include shielding against radiation.

4 Bjarne Chr. Jensen and Henning Laustsen, *Betonkonstruktioner – efter DS/EN 1992-1-1* (Nyt Teknisk Forlag, 2008)

5 Gjørv, Odd. E, (1994), High Strength Concrete, Advances in Concrete Technology, Ed. Malhootra V.M., Canada, CANMET cited in Anja Margrethe Bache, *Ny Betons Form - For Kæmpekonstruktioner*, Post-Doc (Aarhus, Denmark: Aarhus School of Architecture, 2004), 11. In her Post-Doc report about the architectural use of CRC (Compact Reinforced Concrete) the civil engineer and PhD in architecture, Anja Margrethe Bache points out the rapid development of this grade – in the 1950s compressive strengths of 35 MPa were considered high.

As producers, these workers define the quality of concrete production based on its ability to meet the demands of the job in regard to delivery time and technical content. To meet these demands, methods of construction are selected on grounds of efficiency and speed, if not otherwise specified by the client.

Engineers' Concrete

In structural and chemical engineers' understanding, *cementitious composites* is a term that covers a group of material technologies whose common feature is their use of types of cements[6] as the binding agent. Levels of material performance are designed and tested with the ingredients and their ratios determined from a micro-scale down to nano-scales with regard to mix, humidity, temperature etc. Recent distinctions also include *polymers* and *cerams.*

The quality of concrete can be defined in terms of the structural efficiency of the concrete structures in the relationship between geometry, binding and amounts of concrete and reinforcing elements, the durability of the concrete structure as indicated by the density and hardness of the concrete surface, and the absence of cracks.

The quality of concrete structures can be defined in terms of the safe dimensioning required for reinforced concrete structures to carry loads while avoiding shears and deformation and offering protection against different 'forces' of heavy usage, winds, snow loads etc.

Architects' Concrete

Architects, and this dissertation, use the term *concrete* to refer to the gray, liquid substance that hardens into a desired shape and surface defined and supported by a mold. The quality of concrete is considered in terms of the fluid original state of the mix that allows it to reach any virtual form designed in a drawing program. This understanding of concrete is obviously considered as ignorant by the previously mentioned professions as well as a great challenge to the procedures and performance standards they apply. The following introduction to the understanding of what could be defined as architectural concrete is, however, based on a combination of ancient building technology and an impression of the present state of the evolution of forming matter.

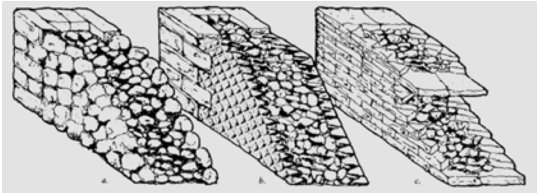
The term *concrete* is based on the etymology of the Latin origin of the word concrete, concrētus, which is the past participle of *concrēscere*, to grow together.[7]

The origin of the word cement, the binding agent in modern concrete,[8] is also important in this regard; it is based on the Roman definition of *caementum*, a mortar with a binding material for constructing walls.[9] The Roman caementum was used in different monolithic structural principles as a binding medium with rocks and brick as aggregate and as a sort of permanent formwork. (1)

A binding medium in mortar is burned lime, but in antiquity the Romans discovered that sand from the town Puzzuolo near the volcano Vesuvius added extra strength compared to commonly used lime-mortar.

Vitruvius describes the process of the 'coalescing' of the materials in the caementum produced in antiquity.

"So the fire and the heat of the flames, coming up hot from far within through the fissures, make the soil there light, and the tufa found there is spongy and free from moisture. Hence,



Three types of Roman walls (a) Opus Incertum (b) Opus Reticulatum (c) Opus Testaceum (1)

Opus Reticulatum and plastered facade, Pompeii, Italy (AMM) (1)

6 In a version of burned and ground lime and silicium.

7 "Concrete" *Dictionary.com* (Accessed 24-11-2011).

8 As opposed to naturally occurring binders in *caementum*

9 " Cement" *Dictionary.com* (Accessed 24-11-2011).

when the three substances, all formed on a similar principle by the force of fire, are mixed together, the water suddenly taken in makes them cohere, and the moisture quickly hardens them so that they set into a mass which neither the waves nor the force of the water can dissolve."[10]

Most famously, the Roman caementum was used to build the dome of the Pantheon almost two thousand years ago; the construction method was forgotten with the fall of the Roman empire, only to be reinvented and developed by 'molders' of surfaces and structures leading to modern concrete.

Molded surfaces and walls

The development of two parallel lines of molded construction describes aspects of the introduction of cast concrete; the development of molded or bound load bearing structures and of molded and rendered decorative surfaces.

The book 'Concrete, the Vision of a New Architecture: A Study of Auguste Perret and his Precursors'[11] is a combination of a monograph on the French architect Auguste Perret and the history of concrete. Here the author Peter Collin emphasizes that the history of concrete must be understood in relation to the mold that gives it shape.[12]

In the late 18th Century the special feature of the French practice of rammed-earth construction, *pisé*, was thus not the use of mud as a material for construction but the process for the 'earth's molding into shape.'[13] The structural practice of the pisé-technique for constructing walls uses a movable wooden formwork system that predicted modern methods of sliding formwork.[14] Decorative practices of molding, at the time, included facades and interiors covered with sculptural and colorful renderings of imitated stone and molded stucco.The structural as well as decorative practices were in search of improved binders, and the patent for the first artificial cement was is fact filed as a 'stucco resembling Portland Stone', a limestone that was quarried on the channel coast of England, on the Isle of Portland, and used extensively for building facades.[15]

The separation of decorative stuccoed surfaces from the load-bearing structure was also reflected in the reluctance to consider a combination of the sculptural use of Portland cement of significance for the load-bearing constructions.

The earliest structural use of cement was as a development of the French molding methods of pisé in wooden formwork, which was named *béton*.[16] As this French *béton* became more liquid and poured, traces of the wooden formwork were visible on the concrete surface. On a rhetorical level, Collins refers to the primacy that Auguste Perret gives to the use of wooden formwork for its significance to imitate timber construction and resemble antique architecture.[17] The decorative (molded) surface of the stucco and the rational load-bearing (rammed) construction begin to unite with Perret's emphasis on the symbolic significance of the surface of the mold.

Structural concrete

The development of concrete as a structural material was initiated with the introduction of iron mesh to ensure frost-proof concrete flowerpots by the French gardener Joseph Moniers in 1849. The French engineer Francois Hennébique (1842-1921) picked up the idea and devel-

10 Pollo Vitruvius, *Vitruvius: the ten books on architecture*, book II–Ch.6.

11 Peter Collins, *Concrete, the Vision of a New Architecture: A Study of Auguste Perret and his Precursors*, 2nd ed. (McGill-Queen's University Press, 2004).

12 Ibid., xxxv The introduction by Réjean Legault.

13 Ibid., 21.

14 Elias Cornell, *Byggnadstekniken: Metoder och idéer genom tiderna* (Byggförlaget, 1970), 257–58.

15 The name since the 1824 patent for 'An Improvement in the Modes of Producing an Artificial Stone' by the English inventor Joseph Aspdin, who invented a material to produce imitation Portland stone.

16 Collins, *Concrete*, 21. A footnote informs that Béton is the term for modern concrete used in French, German (and Danish). The word is derived from the Old French *betum* for a mass of rubbish

17 Ibid., 164.

18 In Breslau, now Wroclow, Poland, built by the city architect Max Berg.

19 James Strike, *Construction into Design: The Influence of New Methods of Construction Architectural Design, 1690-1990* (Architectural Press, 1991), 98–100.

oped an original building system for reinforced concrete, patented in 1892, and initiated the use of reinforced concrete in construction that eventually lead to a search for an architectural expression of reinforced concrete by the next generations of architects and engineers.

TOWARDS AN EXPRESSION OF REINFORCED CONCRETE

The structural statement of the interior of the Jahrhunderthalle[18] (1911-13) included an expressive shaping of the concrete parts that coincided with the formal exploration by the Expressionist architectural movement, and the project demonstrated that reinforced concrete was able to translate the artist's visions to the reality of architecture.[19]

With his 1914 Dom-i-no-concept of pilotis and floating white planes of reinforced concrete, Le Corbusier, who had studied under Auguste Perret,[20] expressed new and revolutionary architectural possibilities in the liberation of the plan of buildings that framed the, now common, notion of fluid spaces. (2)

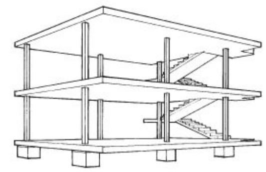
Reinforced concrete has brought about a revolution in the æsthetics of construction. By suppressing the roof and replacing it by terraces, reinforced concrete is leading us to a new æsthetic of the plan, hitherto unknown.[21]

To Le Corbusier, a special quality of concrete was its artificial nature. The industry transforms natural raw materials that are variable in composition into 'new materials' '*(tried and proved in the laboratory)*', which corresponded well with the Modernists' fascination with the performance and aesthetics of the machine.[22]

The German architect Erich Mendelssohn (1887-1953) follows this formal search for the true nature of reinforced concrete as a need to work with the reality of construction[23] and criticized his contemporaries who were members of the Bauhaus Group for having 'rectilinear minds'.[24] The *Einstein Turm* (1917-21) was designed to express the liquid origins of wet concrete as an organic vision of Einstein's Relativity Theory. The reality of construction means that the material properties and the architects' vision must match the experience of the builders who, at the time, were too inexperienced. Shipwrights were called in; they had experience in working with the double-curved surfaces that were used in the construction of the tower.[25] (3)

This interest in exploring the sculptural potentials of reinforced concrete can be summarized in Mendelssohn's three theories: the *Dynamic Condition* and the *Rhythmic Condition*, referring to the plasticity and shape of building, and the *Static Condition*.[26]

"*The equalization of movement, to visualize this as elements of construction*
by means of ground plan and section
Dynamic masses are shown so that their dynamism is clearly expressed so that
movement and counter-movement show the balance
According to the way it is built up, this mass can be mighty oppressive or finely and sensitively outlined without losing its stability"[27]



The Dom-i-no principle by le Corbusier. (2)

Einstein Turm (1919-24), Sketch by Erich Mendelsohn (3)

20 Collins, *Concrete*, 303–4. Perret (1874-1954) built the House in Rue Franklin in 1902, and until the mid-twenties was considered a leader of the progressive architects in exploring architectural expressions of concrete. However, he was never free from the stylistic trappings of the neo-classisicm of the 19th century.

21 Le Corbusier, *Towards a New Architecture* (Oxford: Butterworth Architecture, Org. French 1923/1989), 63.

22 Ibid., 229-232. Alan Colquhoun remarks in "Symbolic and Literal Aspects of Technology", 267 that for the Modernists as for other periods of architecture, the admiration of the buildings of the Modern Movement was caused by their success to display technology symbolically. "*it became part of its content as a work of art and not merely or principally a means to its construction.*"

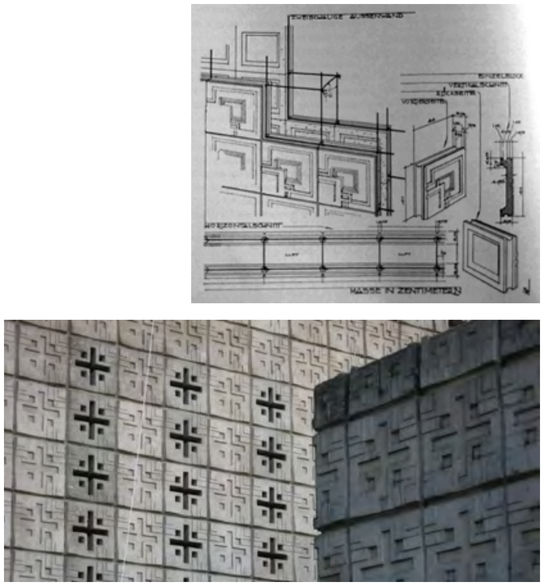
23 Strike, *Construction into Design*, 103.

24 *Sharp, Dennis Mendelsohn and the Einstein Tower,Video, Open University course, History of Architecture and design 18-90-1939, Course index A305,* quoted in Strike, *Construction Into Design*, 102

25 Strike, *Construction into Design*, 103–5. In fact, parts of the building were constructed as rendering over structural masonry instead of the proposed in-situ concrete. This is an example of the discrepancy, described by Colquhoun (p268), between the logic of forms at a metaphorical level and the solution of empirical problems of construction.

26 Ibid., 105.

27 Ibid., 112–13.



Construction drawing and facade details of textile block house (1923) Frank Lloyd Wright (4)

The conditions are mostly visual and formal. Mendelssohn's early exploration of concrete's sculptural expression are thus as an engagement with the fluid origins of concrete. For the following decades' development of reinforced concrete at a structural as well as formal sense, however 'equilization of movement', 'stability' and 'balance' become the key issues.

The American architect Frank Lloyd Wright explored the use of concrete for sculptural as well as structural purposes. In 1929, he offered this critique of the lack of character in concrete. *"Aesthetically concrete has neither song nor any story. Nor is it easy to see in this conglomerate, in this mud pie, a high aesthetic property, because in itself it amalgam, aggregate compound. And cement, the binding medium, is characterless."*[28]

Wright had by then already engaged in forming and molding reinforced concrete walls between stay-in-place formwork of brick and lava-shingles somewhat reminiscent of *cemaentum* walls. He describes the monolithic construction of the Tokyo Imperial Hotel (1916-22), which proved to be earth-quake proof: *"Large or small, the pieces of lava could be easily hollowed out at the back and set up with the hollow side inside, as one side of the slap-forms for casting the concrete. In this way the three materials were cast solidly together as a structural unit when the concrete was poured into them."*[29]

Wright transferred this construction principle of the stay-in-place formwork to the *Textile Block*, a series of houses built in the United States, including the Alice Millard house, *La Miniatura*.[30] (4)

Wright's Textile Block is an interesting example from the turn of the twentieth century in the discussion of the influence of Semper as well as Textile as metaphor. The interpretation of textile ornamentation as an illustration of Semper's *Stoffwechseltheorie* is exemplified through the transformation of woven textile patterns to carving stone and cast as reliefs into liquid stone made through placing a positive in the form panel; of the metaphorical inspiration of the machine-like production of these repeated and identical patterned blocks into an all-enveloping fabric surface; and for the system of literally *binding* these elements together into a system.

According to Frampton, Wright interprets Semperian theories of textiles and dressing into a concrete cladding system with a repetitive weave-pattern. Frampton points out that Wright describes 'knitting' the blocks together,[31] and that he considers himself as a weaver.[32] It is true that the pattern of weaving can be seen in the interlaced, repeated relief pattern on the blocks. Another layer of such a reading would suggest that Wright sees himself as a contemporary weaver of an industrialized manufactured product.

"At last, here I grasp near end of great means to a finer 'order.' Standardization was the soul of the machine, and here the architect was taking it as a principle and 'knitting' with it. Yes, crocheting with it a free masonry fabric capable of great variety in architectural beauty."[33]

Wright's fascination with the aesthetics of the machine is translated into the architectural vocabulary used to describe the construction principle. An interpretation of the fully industrialized manufacture of textiles is then translated into the repeated casts in the *textile-block system*.

The hollow-block system was turned into a monolithic structure by pouring concrete into

28 Frank Lloyd Wright, *Writings and Buildings* (Frank Lloyd Wright Foundation, 1960), 225. Originally published in the *Architectural Record, July 1929.*

29 Ibid., 202.

30 Pasadena, California (1923)

31 Wright, *Writings and Buildings*, 216.

32 Kenneth Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture* (The MIT Press, 2001), 109.

33 Wright, *Writings and Buildings*, 220.

34 The textile block was a permanent formwork system and of interest to the formwork-tectonic aspect of this dissertation.

35 Hugh Pearman, "Caruso St John/Cover Versions" Interview, *The Architects' Journal*, No. 21, 2005, 32.

36 Ibid.

37 Strike, *Construction into Design*, 22–3.

38 Pier Luigi Nervi, *Aesthetics and technology in building* (Harvard University Press, 1965), 22–23.

39 Pier Luigi Nervi (1965) "Aesthetics and Technology in Building… p. 2

40 Ibid., 3-4.

the hollow space. In this deeply metaphorical understanding of textile notions and principles, one could consider 'La Miniatura' to be the first use of fabric formwork.[34]

Another, recent interpretation of textiles in concrete can be seen on the façade of the Nottingham Contemporary Art Centre by Caruso St John (2009), located in Nottingham's historic Lace Market district. Lace production here was largely done on machine The architects are clear about the use of a specific textile for its symbolic significance related to the history of the location.[35] These features – the lace pattern and the fact that it was machine-made – were construed in the process of producing identical concrete elements serially over a rubber mold made from a digitally manipulated scan of the original lace.[36] Even the semi-tubular shape of the concrete façade panels seems to mimic textiles on the production rolls inside the factory buildings. (5)

Pier Luigi Nervi

The Italian engineer Pier Luigi Nervi has a different approach to the fluidity of concrete in which the material is required to express more than merely its liquid origins. In the early 1960s, Nervi sums up the potentials of the artificial 'superstone' as characterized by its a semifluid production properties and its static unity.[37]

To Nervi, this combination of expressive and structural characteristics adds the fluidity of the shapes of "*reinforced concrete beams [*that*] lose the rigidity of wooden beams or of metal shapes and ask to be molded according to the line of the bending moments and the shearing stress.... In short, all the elements of a structure in reinforced concrete have some static or construction suggestion to propose, which can be transformed into a model of expressive aesthetic appearance and shape*." [38]

Pier Luigi Nervi used the phrase to 'build correctly'[39] to emphasize the moral obligation of achieving good architecture within the complex relationship between the key conditions of stability, durability, function, and maximum results by minimum means. And he elaborates: "*respect for technology and economic efficiency constitutes a basis of the correctness, and I would add the ethics, of building. Without such respect it is impossible to achieve a valid architectural expression*." [40]

Nervi is considered a master of shell structures.[41] In his patented construction system called 'structural prefabrication'[42] the construction of large reinforced concrete structures were broken down to equal parts or a series of equal parts that were prefabricated and later assembled and made monolithic.[43] Nervi describes the system as an exploration of the 'plastic richness of prefabricated concrete' and that the method forms both a structural and an architectural unity.[44]

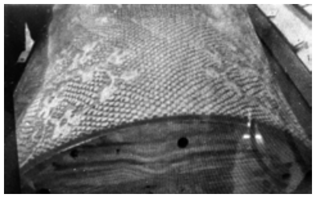
The Nervi method is special because it exploits the plastic richness of concrete in the incorporation of concrete in different conditions (cured prefabricated elements and concrete poured on site) as well as different tectonic principles (tectonics of linear elements and the 'suspension' of a shell).

Nervi's understanding of construction as the relation between structural aims and rational processes of construction is an exploration of fluidity of construction.

The structural grids in Nervi's architecture can be categorized as 'textile' so also Nervi could have called himself a weaver. At a smaller scale, Nervi literally explored a textile way of forming

Detail of concrete surface. Interpretation of pattern and manufacture of specific lace through digital scanning and manipulation leading to rubber mold and cast in fiber-reinforced concrete. Caruso St John 2009

Below, details of the rubber mold photographed from an online video playing on a computer screen. (Youtube.com/Nottinghamm Contemporary Lace Concrete.mov, Accessed 24-02-2012) (5)



41 Heinz Isler, "Shell Structures: Candela in America and What We Did in Europe", in *Seven structural engineers: the Felix Candela lectures*, red. Guy Nordenson and Terence Riley (The Museum of Modern Art, 2008), 89.

42 Tullia Iori, *Pier Luigi Nervi* (Milan: Motta Architettura, 2009), 23–149. Patented in 1939.

43 For example in Pallazio dello Sport, Rome (1956-57). Here, thin ferrocemento coffers, rhomboid hollow flat block, were prefabricated on site; they were simple to handle by workers and functioned as stay-in-place formwork.

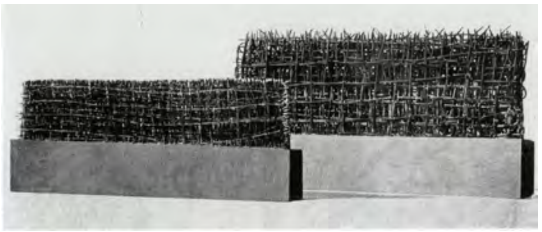
44 Nervi, *Aesthetics and technology in building*, 97.

45 The expression of the author of Iori, *Pier Luigi Nervi*, 23.

46 Francisco Arqués Soler, *Miguel Fisac* (Madrid, Spain: Ediciones Pronaos, 1996), 247. Fisac patented the system in 1950s but did not use it with concrete until the 1960s, for example in the Rehabilitation Center, Madrid (1969)

47 Ibid., 133–34. The beams for *Center for Hydrographic Studies*, Madrid (1960-63) were 22 meters in span, 6-cm thick and precast in one meter long elements and then *post-tensioned*. They display Fisac's focus on prefabrication, assembly and patents tied to the advances in the field of pre-stressed concrete

48 For the principles and construction of the *Bones*, see the catalogue for the exhibition. "HuesOs Varios" (*Several Bones)* Fermín González Blanco, *Miguel Fisac : HuesOs Varios*, (Madrid: Fundación COAM, 2007).



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Top: Sequence of precasting ferro-cement pans. Australia Square, Sydney (1961-67) Harry Seidler with Pier Luigi Nervi (Drew and Frampton, 122)

Right: Ferrocement 'felt' patented by Pier Luigi Nervi in 1943 (Iori 2009) concrete when he invented the technique *Ferrocement* in 1943. In this technique, mats of iron mesh are formed over a mold or falsework and 'babtized' in cement-rich concrete.[45] This rather textile concrete forming technique was tested for small thin -shell structures and was developed for use in mass-produced prefabricated thin concrete elements as part of his method of Structural Prefabrication. (6)

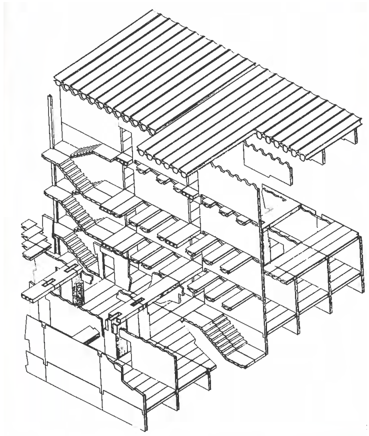
Miguel Fisac and Bone Beam elements (7)

STRUCTURAL BONES AND EXPRESSIVE SKIN

The Spanish architect Miguel Fisac (1913-2006) had a more than 60-year long career during which he explored the use of concrete in architecture; exposed concrete for load-bearing structures cast in situ, prefabricated post-tensioned beams, and decorative facades. He is relevant here because he is the first architect known to use flexible formwork for expressive purposes.[46] Also, because Fisac's earlier work exemplifies architectural use of concrete, in which sculptural and structural potentials of concrete combined with processes of construction.[47]

To engage on Fisac's structural work, he developed a type of beams inspired by the structure of the hollow bones of vertebrate animals. The *Bone Beams*[48] were constructed on site in serially produced elements and prestressed. (Illustrated on this and the next page)

The concrete *Bone Beams* can be understood somewhere in between of concrete as mass or structure. They can be defined as particularly architectural elements because they are designed to handle more functions besides providing a large span; they also include considerations of solar shading and 'water treatment,'[49] and they have strong ornamental features as part of the building structure.



8

Fisac developed several specific bone beams for different projects and devised and patented entire construction systems of hollow concrete *bone elements* for the construction of walls, decks, steps for stairs, and *brise soleils* facades.[50] (7-8a-c)

Of the *Bone Beams* Fisac said:

"*To date, I am not aware of any similar experiments to the ones I am carrying out with these architectural and structural characteristics together, although there are a number concerning one or the other separately.*
Of course these demands to which the pieces are subject greatly reduce their formal freedom. I believe, however, that far from being a disadvantage for the development of genuine plasticity for this material, it is a very beneficial that takes architectural forms away from formal frivolity of a sculptural or pictorial nature which is currently employed. Perhaps it can provide a real fount of genuinely architectural forms." [51]

Fisac criticized the Modern Movement because of its "*abstract plasticity, without any reference to the physical, cultural, and social setting.*"[52] Interestingly, Fisac sees the sculpted concrete architecture by for example the Brazilian architect Oscar Niemeyer as an example 'formal frivolity'; this critique gets a different 'spin' in regard to his own sculptural exploration of concrete, which he considers as ways to express the 'genuine plasticity' of concrete. it is in this search for concrete's expression that Fisac develops and patents 'flexible formwork' as a 'real' and 'tactile' way for the concrete to take on the properties of a smooth sheet of hanging plastic.[53]

49 Beams are designed with an inclination of the top that allows rainwater to run off while still allowing the beams to be placed horizontally.

50 IBM Headquarters, Madrid (1966-69)

51 Soler, *Miguel Fisac*, p 145. 'A Few Thoughts' by Miguel Fisac, 1967, in which he praises the architectural possibilities of concrete over rolled steel as points to the degree of difficulty and possibilities as reasons for the unfulfilled opportunities.

52 As quoted in (1989) "La Obra de Miguel Fisac". Documentos de Arquitectura nº 10. Colegio de Arquitectos de Almería IN Miguel Fisac, "Fundación Miguel Fisac", u.d., http://fundacionfisac.org/

53 An interesting aspect of Fisac's oeuvre to keep in mind is the fact that he lived and worked in Spain during wars, revolutions, and changing religious and political environments, including the forming of a republic, the Francoist dictatorship (1936-1975). Seen in this light, the elaborate voluptuous concrete cladding that Fisac used most extensively in the 1970s may symbolize the desire to release more than the fluid concrete from its rigid formwork.

(8c)
(8a)
(8b)

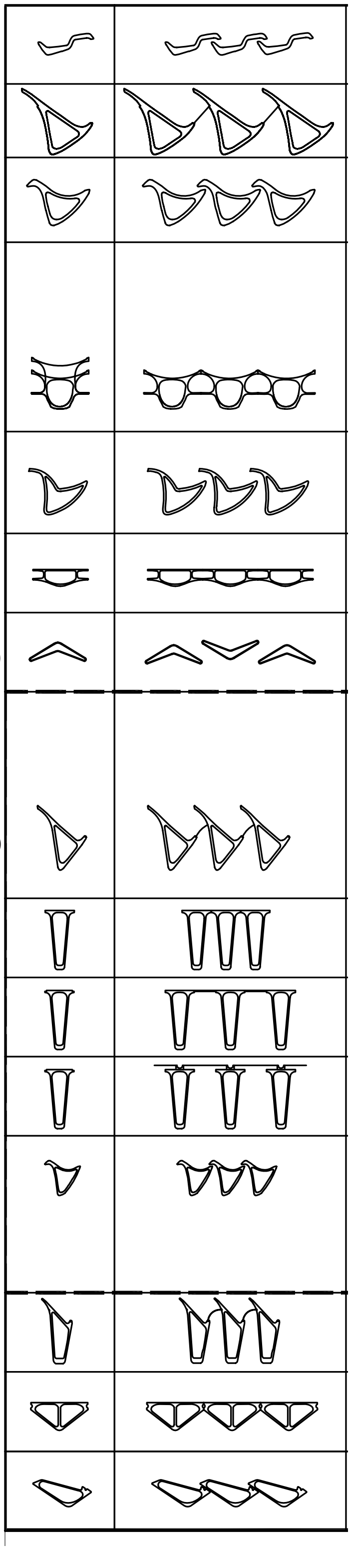
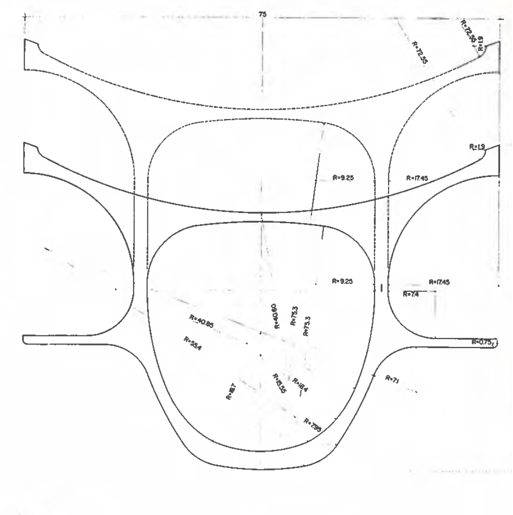


Table of Bone elements listed chronologically from the top, 1960-70s

8.a
Brise de Soleil facade in V-shaped 'bone' elements, IBM Office, Madrid. (Image below, from AV101, the remaining images: AMM)

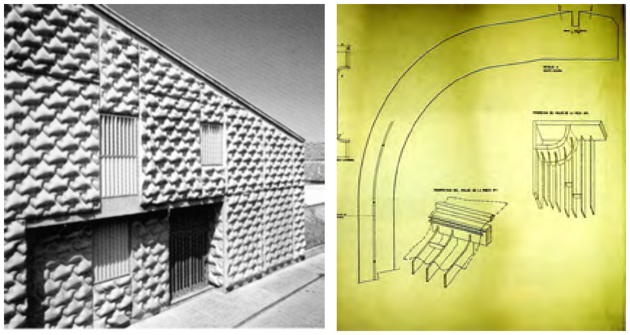
8.b
Light-diffusing bone beams and cantilevered steps in Center for Hydrographic Stucies, Madrid



8c
Bone Beams, Santa Ana Church, Madrid. Drawing that shows the section of each end of Bone Beaam. The bone beams are conically shaped to allow rainwater to drain off and still maintain horizonatal placement of beams.

"Concrete is the only material which is applied in a work in a different state as its final one (paste). This paste condition should be remembered in its final state, as a genetic print of a material that was first soft, being later cast in a mold which gave it its final shape a texture."[54] The concrete elements, which are cast in 'flexible formwork', function as decorative and tactile surfaces – heavy and voluminous façade cladding. As such, the elements are sculpturally expressive of the fluid origins of concrete and the flexible plastic sheet. (9)

The formwork material is, however, not challenged in the process like the wooden boards that formed the rotating geometries for the office tower the '*Pagoda*', [55] (10) cast in situ. The use of flexible formwork also does not contain the combination of structural *and* expressive qualities of the *Bone Beams*. As structural types, these moldings in flexible formwork can be categorized as ornamental stucco.



Facade and work drawing for flexible formwork, Miguel Fisac (9)

Construction of the '*Pagoda*', Office tower, Madrid 1955, MIguel Fisac. (10)

STEREOGENEOUS CONSTRUCTION

A stereogeneous approach to the construction of concrete architecture is tied to the understanding of a series of conditions during the becoming of concrete structures. It lies between the overall conception of formal archetypes and the construing and construction of its components.

A stereogeneous approach considers the relationship between traces of construction and the formwork tectonics for construing and constructing architectural space, structure, surface, and sculptural form.

Architectural spaces and surfaces of a sculptural solid are defined by the reversal of positive and negative spaces of the formwork to become solids and voids in cast concrete. Voids in a monolith concrete are created by the *removal* of imagined mass and constructed through the articulation of recesses and block-outs in the formwork through an *addition* of structure within the formwork. Similarly, concrete shells, which may be expressive and structurally efficient, tend to require large amounts of falsework.

Stereogeneous space

The small Brother Claus Field Chapel[56] by the Swiss architect Peter Zumthor (1943) clearly displays conditions of stereogeneous architecture, in which a prominent feature is the expression of processes of the rhetorical and technical becoming of space and structure.

The following is a fairly instrumental, almost archeological reading and interpretation of traces and of the technical and technological roles of formwork tectonics and illustrated on the following page. (11)

The architectural space is created from basic spatial as well as structural principles of erecting a teepee-like structure[57] of wooden rafters. This structure is then turned into a cave-like monolith, as the teepee-falsework is covered in layered pours or, more accurately, sections of rammed 'earth-dry' concrete.

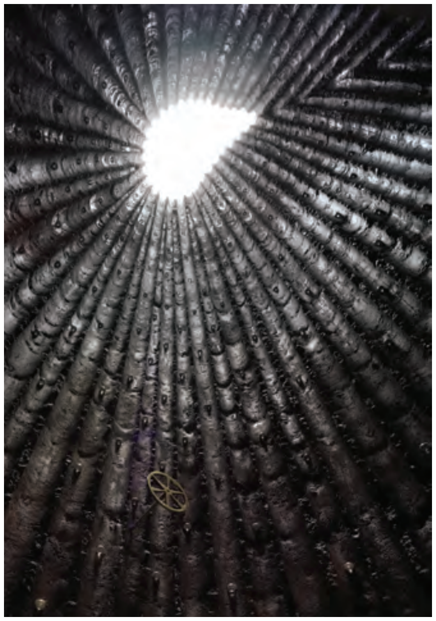
The dry concrete surface reveals the aggregate stones on the exterior of the chapel; the lines between the 50-cm layers reveal the processes of ramming. Holes penetrating the wall appear as symbolic traces of the sliding formwork method of *pisé* construction. They are emphasized with small pieces of glass.

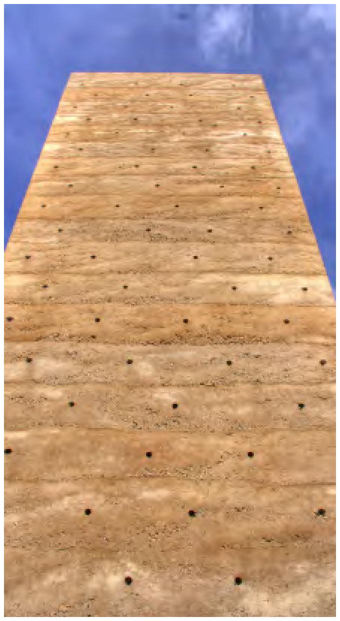
54 Miguel Fisac, "Conception and Construction of Buildings from the Architect's Point of View", in *Proceedings of the Ninth Congress of the Fédération Internationale de la Précontrainte* (Stockholm: Fédération Internationale de la Précontrainte, 1982)

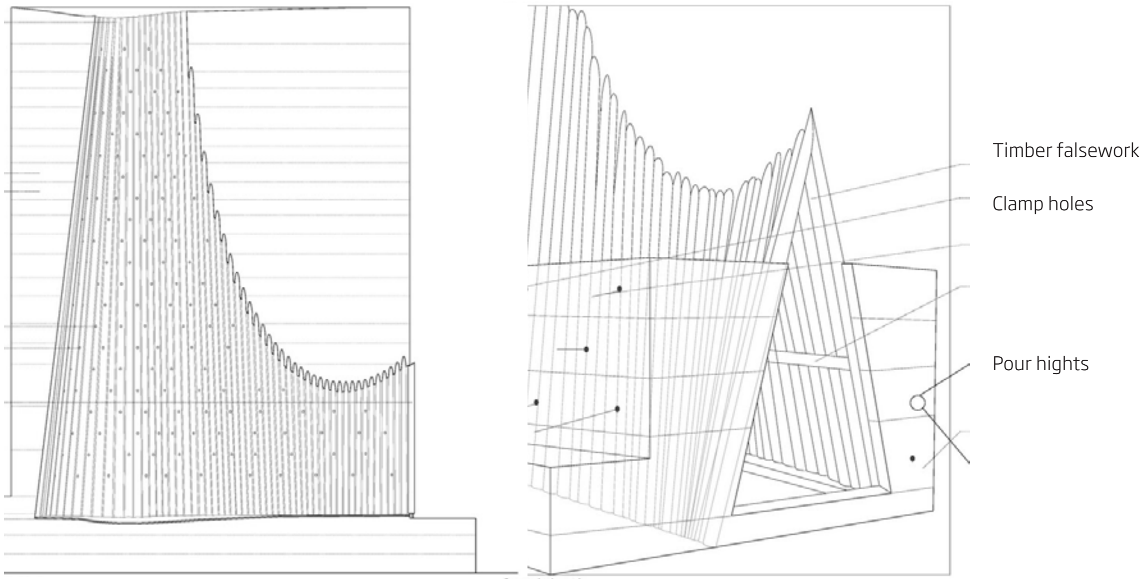
55 Madrid 1965

56 Peter Zumthor, *Brother Klaus Field Chapel*, Architecture, Chapel, 2007, Mechernich near Cologne, Germany.

57 Merriam Webster Online Dictionary, falsework: temporary construction on which a main work is wholly or partly built and supported until the main work is strong enough to support itself







11
Top: Brother Klaus Field Chapel clearly expresses elements, conditions of becoming: the layered pours [construction joints], the aggregates of the dry concrete mix, and the interior space with surfaces showing the space-making wooden rafters and the charred black concrete, which indicates the slow fire that eliminated the formwork.

Bottom, longitudinal section and construction isometric (Nalbandyan 2010)

A striking aspect of the stereogeneity of the project is the charred interior. The wooden rafters have a stereogeneous consistency in the assembly and curvature of the individual wooden elements. The removal of the interior space-defining wooden falsework is revealed to the senses through the visual evidence of the black walls and the accompanying faint smell of burned wood from the smoldering fire, which consumed the falsework over a period of three weeks.

Zumthor's chapel was constructed on falsework and did not include an all-embracing formwork shuttering for a concrete pour. This direct relationship between the falsework and the architectural space makes the project simple to explain.

For certain projects that have been cast in situ, drawings are difficult to classify as either construction drawings or design drawings. They are stereogeneous drawings.

Stereogeneous structure

The seminal building for the laboratories of the Salk Institute (1959-66) by the American architect Louis Kahn (1901-74) displays sensibility toward the stereogeneous potentials of formwork tectonics. Kahn's expressive approach includes careful planning to control and emphasize the processes of construction:[58] Kahn's office produced hundreds of drawings defining the precise sizes and positions of all formwork sheets and form-ties; V-shaped protusions articulate joints between formwork sheets.

Kahn describes a detail of construction *"All the forms are made out of four by twelve plywood, and at the joints the concrete bleeds out. This gives the opportunity for the concrete to be relaxed in its forming itself; not to be restrained in any way at the points where it cannot be restrained. Allowing it to go through actually perfected the concrete at the joints…"*[59]

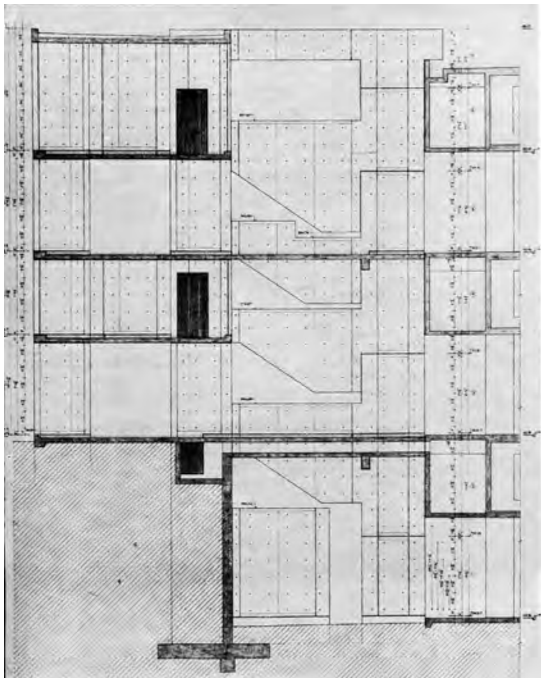
Specifications indicated the height that each stage of concrete pours should reach; formwork sheets were coated for a smooth surface; Kahn achieved a warmer gray colored concrete by adding a small amount of pozzuolana to the mix. The precision of the formwork construction is contrasted by the lack of post-treatment of the concrete surfaces after pours; only the tie-holes were filled with lead plugs.

Kahn later said, "*You must really know the nature of concrete, what concrete really strives to be. Concrete really wants to be granite but can't quite manage. Reinforcement rods are the play of a marvelous secret worker that makes this so-called molten stone appear wonderfully capable – a product of the mind.*" * (12+13)

Stereogeneous surfaces

The 'elephant skin' was originally a stereogeneous consequence of the experimental use of materials used as slip-agents[60] for early 'tilt-wall' construction of concrete wall elements for the Schindler House.[61] More than eighty years later, the French architect Jean Nouvel was inspired by the surface effect and applied it as decoration of the foyer of the Danish Broadcasting Corporation's Concert Hall by.[62] Here, a form-lining membrane placed in rigid formwork wrinkles and add shine to the exposed concrete interiors of the building. (14)

Despite the completely nonstructural function of the form liner, the example contains an interesting aspect for a stereogeneous reading.



12
Working drawing. Salk Institute, 1959-65, Louis Kahn (Ronner et al 1977)

58 Robert McCarter, *Louis I Kahn* (Phaidon Press, 2005), 197–98.

59 Louis I. Kahn, "Address - 5 April 1966", in *Louis I. Kahn: Writings, Lectures, Interviews*, ed. Alessandra Latour (Rizzoli International Publications, 1991), 216. About the construction of the Salk Institute.

* Louis I. Kahn, "I Love Beginnings", 1972, in *Louis I. Kahn: Writings, Lectures, Interviews*, 288.

60 "Elephant skin for the concert hall - Newsletter - MT Højgaard", u.d., http://mth.com/About-Us/News/Newsletter/Archive/Elephant-Skin-For-The-Concert-Hall.aspx. (Accessed 15-12-2011). Press material from the contractor describe how materials, such as soap, fabric and newspapers were placed in the molds to ease the release of the concrete element from the mold.

61 Rudolph M. Schindler, *Kings Road House, "Schindler House"*, Architecture, Residence and Studio, 1921, West Hollywood, California, USA.

62 Jean Nouvel, *Danish Broadcasting Corporation's Concert Hall*, Architecture, Concerthall, 2006.

Salk Institute, 1959-65, Louis Kahn. lead tie-hole and shadows cast from the 'bleeding' concrete that articulate joints between formwork boards (Gast 90) (13)

'Elephant skin.' Concrete surface cast against rigid formwork with plastic membrane lining, Vertical lines indicate the vertically poured concrete. DR Concert Hall, 2006, Jean Nouvel. (14)

The surface principle of the 'elephant skin' itself is evidently cast in plastic. The technique has been used on the in situ as well as the prefabricated elements in the foyer; the deformation of the membrane sheet inside the formwork varies greatly between the concrete walls cast *vertically,* in situ, and the concrete wall elements cast on horizontal *surfaces* as prefabricated slabs.

The surfaces of the walls cast in situ all show vertical wrinkles and lines caused by – and in this regard indicating – a vertical pour. The surfaces of the walls cast horizontally instead display how the form liner was placed before the pour. In this way, the oversized form liner has the intended smooth wrinkle effect but also enhances the *geneity* of the concrete walls.

Stereogeneous form and textile thinking

The previous examples have expressed the geneity of concrete form, structure, and surface constructed over distinct falsework or formwork and displaying a careful attention to the pour.[63] The *Gate House*[64] in New Canaan, Massachusetts (1995) by the American architect Philip Johnson (1906-2005) expands the structural role of reinforcement of concrete *after* construction to include an important role of 'reinforcing' the formwork *during* construction.

The shape of the structural walls for Philip Johnson's Gate House[65] in New Canaan, Massachusetts, was constructed like a jigsaw puzzle with pieces of rigid polyurethane insulation boards. On each side of the PUR boards, reinforcement mesh is mounted as a sandwich construction around the permanent formwork; layers of shotcrete then protect the reinforcement. Just like plastering, the first layer of sprayed concrete stiffened the assembly of interior panels and enabled most of the templates and the scaffolding to be removed. The second layer of concrete gave the wall the necessary thickness and provided the necessary cover to the reinforcement. (15)

"*The outcome of this reversal, in which the formwork is suddenly on the inside, is an apparently monolithic, thin-wall concrete shell. This method of construction in which the design can be manipulated during the building process renders possible the dream of plastically deformable, insulated concrete*." [66]

The basic principle is related to some of the original ways of construction using spatial lattice works and making the structure rigid with clay. To the Swiss architect Andrea Deplazes (1960), this method of construction, with the use of two material conditions, rhetorically 'releases' concrete from its formwork; using flexible but relatively stable reinforcement mesh and fixing the structural shape with shotcrete "*implies the possibility of a free, biomorphic workability of reinforced concrete – comparable to the process of modeling a lump of clay in the hand*."[67]

The inner forming and structuring structure leaves no stereogeneous traces from a pour, a filling procedure. The layers of sprayed concrete literally add degrees of sculpting and surfacing to the inner structural and insulating core. This example and Deplazes' dream illustrate the aim in the dissertation to develop a notion of formwork tectonics based on minimizing the number of formwork elements without a dual-sided technological role and an maximization of the roles of existing formwork elements. Instrumentally, the blocks of insulation and the reinforcement mesh for shotcrete structures have achieved a structural role as permanent

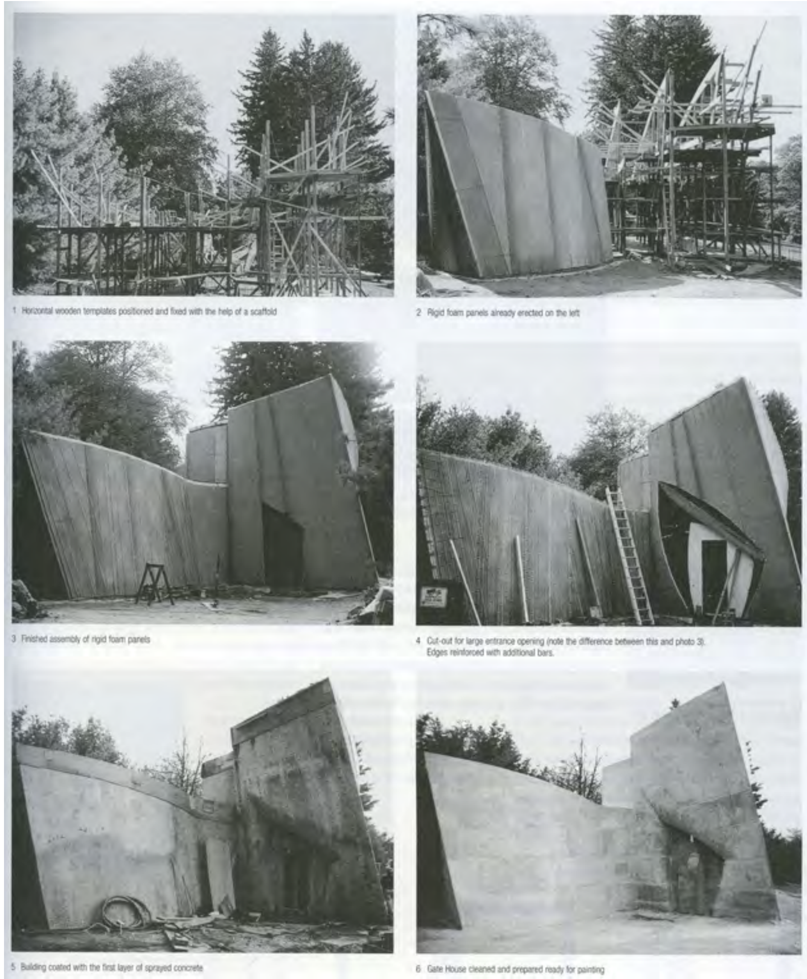
63 And 'ramming'.

64 Nicknamed 'Da Monsta'

65 Philip Johnson, *Gate House, "Da Monsta",* Architecture, Building, 1995, New Canaan, Mass., USA.

66 Andrea Deplazes, ed., *Constructing Architecture - Materials Processes Structures, a Handbook*, 2nd ed. (Basel: Birkhäuser, 2005/2010), 140.

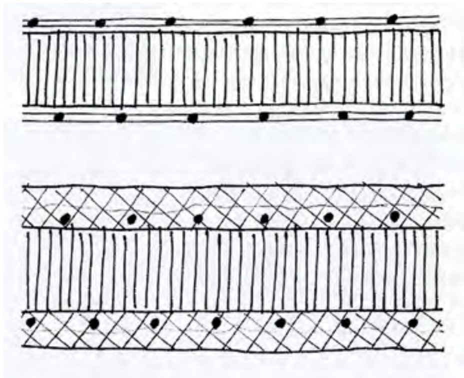
67 Ibid., 59.



1 Horizontal wooden templates positioned and fixed with the help of a scaffold.
2 Rigid foam panels already erected on the left.
3 Finished assembly of rigid foam panels
4 Cut-out for large entrance opening (note the difference between this and photo 3). Edges reinforced with additional bars.)
5 Building coated with the first layer of sprayed concrete
6 Gate House cleaned and prepared ready for painting

(Deplazes 2005, 141)

15



Sketches of wall construction (horizontal sections) for Gate House, New Canaan (USA), 1995, Philip Johnson.
Top: the rigid PUR foam insulation between two layers of reinforcing mesh serves as permanent formwork. Bottom: rigid PUR foam insulation panel covered with two coats of sprayed concrete both sides. (Deplazes 2005, 140)

Frederick Kiesler working (1964) Photo: www.frederickkiesler-estate.com

formwork. The notion of the interior formwork adds layers of *rhetorical* significance to these forming agents.

In this regard it is also an example of textile stereogeneous thinking that is comparable to the thinking of the Austrian artist Friederich Kiesler (1890-1965), who similarly conceived and constructed seamless spaces in his visions of the Endless House.[68] The built models for the floating spaces were developed from a structural and formgiving core through the properties of a pliable metal mesh that was later covered and rigidized with plaster. (16)

Ben van Berkel and Caroline Bos of the Dutch architectural office UNStudio acknowledge the influence Kiesler's influence on the architectural scene.[69] They find the essence of Kiesler's Endless House to be its '*capacity for endlessness*', which is expressed by the fact that the material to build the structure was unexpressed.[70] In two buildings by UNStudio a form of 'textile thinking' forms the structural and programmatic concrete surfaces in Möbius House[71] and Mercedes Benz Museum.[72]

Summing up

Stereogeneity is concerned with concreting and with formwork tectonics, the careful relation between formwork principles according to the properties of the specific formwork material and techniques.

Concreting deals with the factors concerned with pouring or spraying concrete and relates, to some extent, to the construction principle for the entire built structure. Is it a monolith cast in place, or a structure comprised of elements?

The stereogeneous consequence in construction with fabric formwork, the expression of textile notions and formwork principles, lays the foundation for a new focus on the expression of elements in the process of construing and constructing architecture. The introduction to textiles as formwork may set the scene for reinventing textile principles in architectural molding. The range of stereogeneous examples have been selected to illustrate how concrete's 'handful' of parameters can be used to generate architectural structures, form, and surfaces.[73] The introduction of several 'textile' projects are considered relevant for to the study of fabrics as formwork because the textile thinking that is present in these projects illustrate symbolic and literal aspect of textile technologies in concrete. The point is that an architectural implementation of fabrics as formwork will include the interpretation of either processes or expression in the same kind of reverse Stoffwechsel illustrated in Mendelsohn's Einsteim Turm.[74]

68 Frederick Kiesler, *Endless House*, Sculpture, Models, 1959, Austria.

69 Footnote in Valentina Sonzogni, "Frederick Kiesler et la Maison san fin / Frederick Kiesler and the Endless House", in *L'architecture d'aujourd'hui, N° 349 Novembre-Déce : Question de forme : Shapping Form*, ed. Axel Sowa (Jean-Michel Place, 2003), 57.

70 Ibid., 55. Van Berkel and Bos cited

71 UN Studio, *Mobius House*, Architecture, House, 1998-1993, Het Gooi, Netherlands.

72 UN Studio, *Mercedes-Benz Museum*, Architecture, Museum, 2001-2006, Stuttgart, Germany.

73 The 'handful' approach, illustrated on page 49, consists of Aggregates, reinforcement, mold material and surface. Three examples illustrate 'aggregate' as a stereogeneous approach. 1. The transluscency in Light Transmitting Concrete in which light transmitting fibers are layered in the formwork, 2. the possibility to cast truely monolithic concrete structures when porous clay and glass is added to the concrete mix to add insulating properties. This technology is used in Swiss concrete architecture by fx Patrick Gartmann in his own house in Chur (2003). The additional cost for the special concrete mix is met with a trimming of the procedures and details of construction. 3. the surface effects caused by retarder chemicals and printing tech niques in the product Graphic Concrete. Here, the chemical retards the curing of cement paste and colored or uncolored aggregates are exposed in a grapfic pattern when the uncured cement is hosed down.

74 Reverse, because the expression in these examples illustrate the formal potential of a new technique and not, as Semper's theory suggests, carry ornamental traces from a preceding mode of construction.

TEXTILES IN CONSTRUCTION

Viaduct over the Basento River, Potenza Italy, (1967-76)
Sergio Musmeci . Left, a hanging membrane model.

A FAMILY OF TEXTILE CONSTRUCTION

The following introduction to textiles used as skin in construction is based on a categorization by Chandler & Pedreschi.[1] The 'family of textile construction' is divided into four categories: Tensile membranes, pneumatic structures, hydrostatic fabric formwork, and shells derived from membrane form-finding.

The categories will be briefly described and supplemented with a note on Heinz Isler's definition of *analytical* and *experimental shapes* and an the introduction to technical textiles.

In *tensile membrane structures*, typified by Frei Otto's legacy to engineering, fabric is used to create an optimized form and a minimal surface between fixed points. The fabric has self-organizing properties but requires manipulation by the fix points to render a uniformly tensioned surface. *Pneumatic structures* are vessels for air under pressure. Any form can be obtained, from pure domes (see the Bini Shells to the right) to cartoon characters, depending upon the level of precise tailoring.[2]

Structures can also be designed using fabric as *form-finding device*. This technique uses catenary principles of rigid hanging chains inverted to obtain the geometry for double-curved structures under pure compression achieved in concrete or grid shells, such as Mannheim Multihalle (1975) by Frei Otto.

In *hydrostatic fabric formwork*, catenary curves are automatically generated when concrete is poured into the fabric, which deflects between restraining points. Chandler points out the significance of the fact that in hydrostatic formwork the fabric acts as both *form-finder* and *form-giver*; this indicates the direct relationship between the conception of the optimal form and its construction.

Analytical and experimental shapes in form-finding

The Swiss engineer Heinz Isler (1926-2009) developed form-finding methods in which the natural deflections of hanging membranes in tension may be used to develop the geometry for shells that act under compression when the structural shape is inverted.[3] The initial formfinding procedure is simple and involves the self-organization of materials. The following empirical tests and calculation processes are however time consuming. Large minimum surface shell structures have been built but with rigid, wooden falsework.

Heinz Isler differentiates between structural shapes that are analytical, i.e. shapes derived from mathematics and geometry such as a cylindrical shell, a rotational shell, or a hyperbolic shell, and ones that are experimental: shapes derived through a process of creative play that leads to models of hanging chains, pneumatics, flowing shapes, and hanging reversed shapes.

Most shells made up until the 1960s was designed as analytical shapes. Of the structural aspect of experimental shapes, Isler states

1 The following description is based on Chandler and Pedreschi, eds., *Fabric Formwork*, 7.

2 Pneumatical and automated construction systems by architect Dante Bini are also mentioned in the next chapter but illustrated here. His work might as well have been introduced in the previous chapter as issues of concrete and 'fluidity' of construction overlap.

3 John. Chilton, *Heinz Isler* (Thomas Telford, 2000)

4 Isler, "Shell Structures," 100. Isler's principles and belief in the excellence of the form-found shells have inspired work at Center for Architectural Structures and Technology (CAST) at the University of Manitoba. See the analytical study of the *Fabric-Formed Rigid Mold.*

5 "History of Plastics and Plastic Packaging Products - Nylon", n.d., www.packagingtoday.com/intronylon.htm. (Accessed 17-11-2011). Nylon, the trade name for polyamide, was the first purely synthetic fiber, introduced by DuPont Corporation at the 1939 World's Fair in New York City.

"These are what I call the structural shells because they follow the forces that nature needs, that physics needs, that static needs; and therefore they are far better than the others. The others are good and useful, but these can lead to excellent results."[4]

The Italian engineer Sergio Musmeci (1926-1981) designed a concrete bridge, the viaduct over the Basento River, Potenza Italy, (1967-76) illustrated on the previous page. The design of the bridge applies a playful combination of principles from tensile construction and membrane form-finding. From tensile construction comes the required manipulation of the membrane in fixed points, and from the form-finding use of hanging models comes the natural deflection into catenary curves.

Technical textiles and polypropylene

Recent technological developments with regard to textile materials and production methods have led to a wide range of textiles that have specific technical properties (such as strength and size) and which can be produced at a price that make them suitable for use as formwork.

The introduction of strong lightweight nylon[5] and polyolefin[6] textiles between the 1930s and 1950s marked the advent of a new type of high-performance textiles referred to as technical textiles.

"*Often referred to as technical textiles, these high performance fabrics are among the most innovative examples of design today. Textiles are everywhere, yet they are often concealed under roadways, behind walls, in concrete, and even within our bodies… Pure function is their purpose, and success is determined by their ultimate performance.*"[7]

One widely used material in technical textiles is polypropylene (PP). This material was introduced commercially in 1957, and since then it has become one of the most widely used plastic materials.[8] Short PP-fibers are used as concrete reinforcement,[9] and the material is widely used in parts for machinery, furniture, tubes etc.

Woven sheets of polypropylene belong to a group of technical textiles described as geo-synthetics or geo-textiles. The name geo-textiles implies its intended use, which is to be placed in the ground, where it functions as reinforcement under pavement and in roadsides.

Woven geo-textile has a high tensile strength and little elongation. It is produced in 'endless' sheets, and it is lightweight and cheap.[10]

One commercial application of PP-weaves is to assist the construction processes rather than a construction material as such. PP-weaves are sewn into heavy-duty bags for the transportation of bulk material.[11] The same properties have also made it possible to use sheets of woven polypropylene as formwork to cast concrete structures.[12] The porosity of the weave and the hydrophobic property of the materials let the fabric act as a filter under hydrostatic pressure.[13]

6 Olefin fibers (polypropylene and polyethylene) are products of the polymerization of propylene and ethylene gases. First U.S. Commercial Olefin Fiber Production: 1958, olefin monofilaments for various specialized uses, "Olefin Fiber," *FiberSource*, n.d., http://www.fibersource.com/f-tutor/olefin.htm.

7 Matilda McQuaid, "Tectonics and Textiles," in *Architextiles*, vol. 2006, 6th ed., Architectural Design (London, England: Wiley Academy, 2006), 98–101. Matilda McQuaid, Head of the Textiles department at the Smithsonian Cooper-Hewitt, National Design Museum, was a key note speaker at the Creative Systems Conference, RDAFASA September 2007. Here she described the advances and applications of technical textiles as some of the most innovative examples of contemporary design.

8 H. C. Dam et al., eds., *Materialebogen* (Copenhagen, Denmark: Nyt Teknisk Forlag, n.d.), sec. Polypropylene.

9 Including reinforcing the concrete stuctures produced during the TEK1 workshop in March 2011

10 The prices obtained for the thesis work was 1-2 € per square meter depending on strength of the fabric and length of the roll.

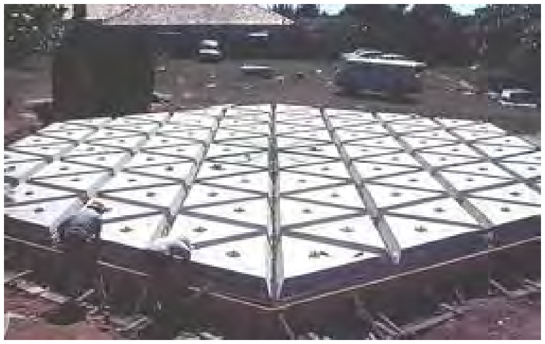
11 www.bluepack.dk (Accessed 4-02-2012). So-called Big Bags weigh ca 1 kg and can carry 500-1500 kg according to specifications of the distributor website.

12 Kenzo Unno of URC Design, Japan; Sandy Lawton of Arro Design, USA and research environments at for example the University of Manitoba and the University of Edinburgh who will be introduced further in the following.

13 Jannie Bakkær Sørensen and Ida Højgaard Wonsild, "Vævet Geotekstil Som Tekstilforskalling (Woven Geo-textile as Fabric Formwork)" (Diploma project, Architectural Engineering, Technical University of Denmark, 2008). Sørensen and Wonsild describe 'water cup' experiments and measurements of the concrete surface with regard to density and 'point-pressure' tests as well as a tensile-strength test of several methods for joining textiles in their diploma thesis. These 'seams' will be introduced presented in the analytical studies.

14 Dante Bini. n.d. www.BiniSystems.com, (accessed 16-11-2011). Images are also from the web site

15 www.concretecanvas.co.uk/. (Accessed 11-10-2011). Images are also from the website.



Top, construction of Bini Dome, above, Binix System. Below, two images of Concrete Canvas.

FLUIDITY IN CONSTRUCTION

Two examples of development

The images to the left illustrate two principles where textiles are used in the automated construction of pneumatically supported concrete shells, work by Dante Bini initiated in the 1960s and a construction principle for shelters using the textile technology Concrete Canvas. Both construction principles combine material with a structural principle and a method of construction. The Italian architect Dante Bini[14] has since a first prototype in 1964 experimented with different forms of automated construction: Pneumatic formwork with the concreting applied prior to inflation, and below, a prototype with prefabricated elements connected on site in a process combining Nervi's Structural Prefabrication with pneumatics.

Concrete Canvas, a british company established in 2005 with the development of a concrete impregnated textile. The product was developed for the automated construction of emergency shelters out of a box. The canvas technology alone has since found application for military purposes as well as design prototypes.

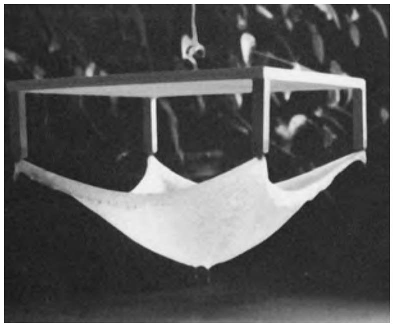
The relevance for the discussion of the development of fabric formwork, another construction method that uses textiles as formwork, is that where the development of Bini's automated construction principles has since moved away from the use of concrete,[15] the key element of Concrete Canvas is in fact the technical concrete impregnated textile. Similar development is likely to occur in the development of principles and applications of fabric formwork.

FABRIC FORMWORK FOR CONCRETE

Characteristics of fabric formwork

History and development

Construction principles



1 2

Left: Deflection of membrane into catenary curves(Heinz Isler).
Right: Water pressed through geotextile during concrete pour. (TEK1 workshop)

3

Square form tie and the stereogeneous consequence (the *Clamp Wall* , appendix 2.1)

1 Diederik Veenendaal, Mark West, and Philippe Block, "History and Overview of Fabric Formwork: Using Fabrics for Concrete Casting," *Structural Concrete* 12, no. 3 (September, 2011): 174..

2 Ibid., 173–74.

3 Ibid., 174. Fabric formwork methods mentioned in the definition *"have also been referred to as "flexible formwork", and less commonly as "membrane", "flexible", "textile" or "fabric mould". The latter two terms may lead to confusion because a "textile mould" can also refer to foam-injected moulds, or formwork for textile-reinforced concrete, and a "fabric mould" can refer to historical methods for the production of paper or pottery"*

4 Ibid. and Bruce Lamberton, "Lamberton Fabric Forms for Erosion Control," Concrete Construction, The Aberdeen Group, May 1980. This approach was first developed in a 1936 for a vacuum device by Karl Billner and in a 1943 patent for a passive system with an absorbent mold liner.

5 Fibertex, n.d., www.fibertex.com. Fibertex Nonwovens is one such product.

6 Here, the use of the word *weaving* covers all textile manufacturing techniques.

After an introduction to the characteristics of fabric formwork for concrete structures, the chapter is divided into three sections: the early historical development of fabric formwork for concrete, recent developments and architectural research practice, and finally the general principles of construction.

CHARACTERISTICS OF FABRIC FORMWORK

Textiles have a high tensile-strength-to-weight ratio. And freshly poured concrete has a high hydrostatic pressure, determined by the height and the rate of the pour. This means that tensioned sheets of fabrics can be used as a lightweight and flexible formwork material for casting concrete.

Fabric formwork has recently been defined as a "*formwork that uses a flexible membrane for the structural support of fresh concrete or rammed earth*."[1] This definition includes soil, air or fluid pressure-supported formwork as well as the use of different types of fabrics such as non-woven membranes. It excludes the simple use of fabric as a form liner.[2]

Throughout the dissertation, the term fabric formwork will be substituted with terms such as responsive formwork, dynamic formwork and membrane formwork. Unless otherwise stated, the meaning is the same; alternative terms are used to offer variation in the writing despite the risk of confusion with other types of flexible molds[3]

Fabric Formwork has three key characteristics: the deflection of membranes into catenary curves, the filter effect of woven textile surfaces, and the direct stereogeneous effect of the chosen formwork principle.

Catenary curves

The shape of a hanging chain is described as a catenary curve.

Membranes deflect into catenary curves in all directions across the surface when exposed to an evenly distributed load such as hydrostatic pressure from poured concrete. This material negotiation between the concrete and the flexible membrane allows the latter to structurally 'organize itself' to a form that achieves equilibrium in relation to the load. The 'allowed' deflection of the surface under pressure makes the membrane an efficient formwork material. (1)

This material behavior makes it possible to cast concrete into very lightweight formwork. Furthermore, the deformation of the textile surface can be controlled through tension. Concrete objects with advanced geometries can be cast from flat sheets of textiles.

Textile filter effect

The porous structure of woven fabrics acts as a filter that leads excess water and air through the formwork membrane. This happens immediately after the concrete has been poured, and the hydrostatic pressure is still high. The release of excess mix water from the fresh concrete mix lowers the ratio of water to cement in the concrete surface, reduces the amount of air bubbles and blowholes, and increases the surface strength of the cured concrete.[4] (2) Fabric liners are placed inside rigid formwork systems.[5] With fabric formwork, the formwork contains this effect.

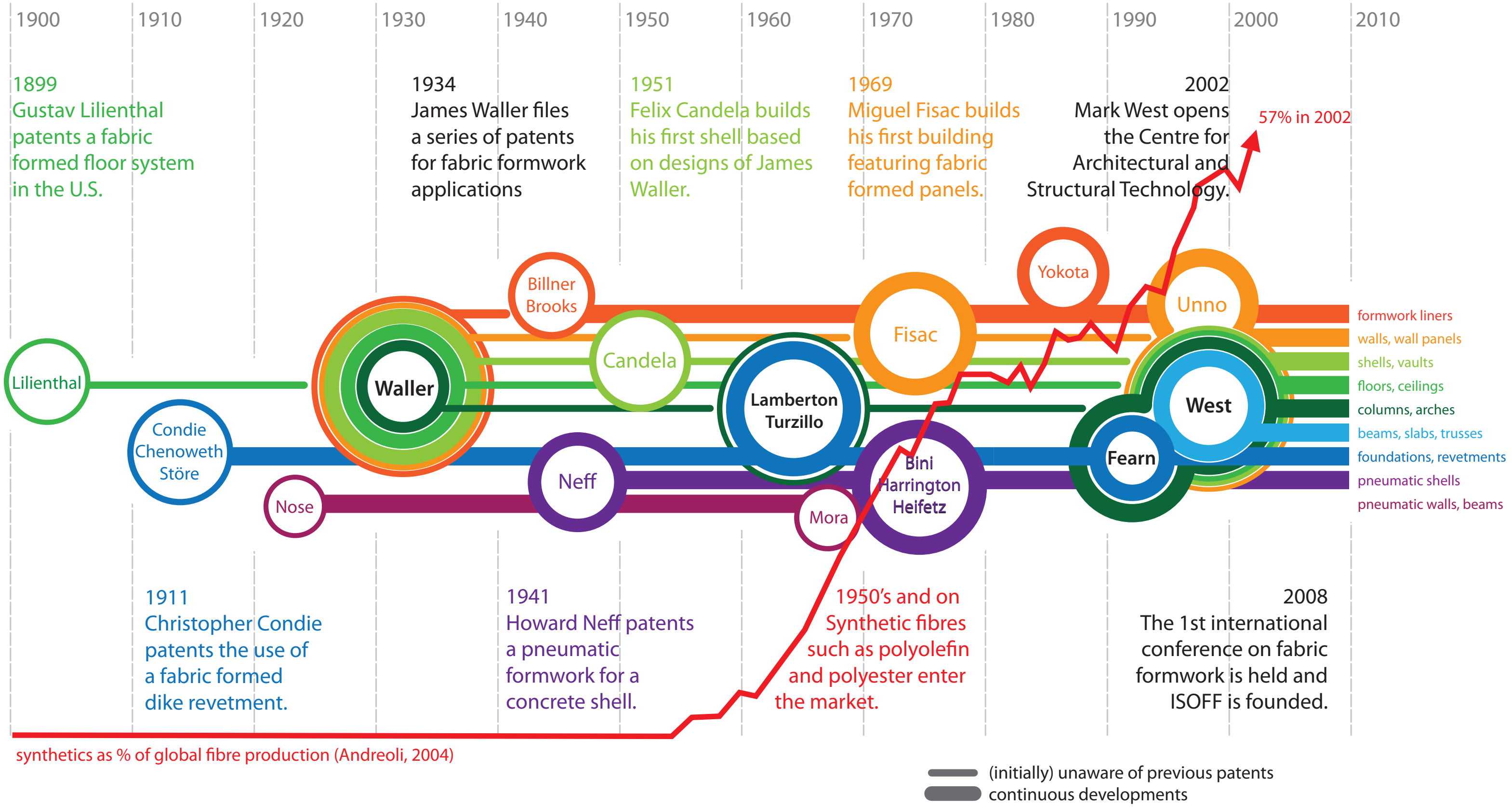


Fig. 4. Timeline of fabric formwork, The figure shows relations between by inventors, as well as a graph of the relative increase in synthetic fiber production. (Veenendaal, West and Block)

Stereogeneous consequence

Besides formal geometry, concrete takes on the characteristics and details of any formwork surface. For fabric formwork, the pattern of the weave,[6] the type of thread used in the weave, the direction or tailoring of the fabric, and the shape and method of restraining and tensioning fabrics become evident in the form and surface of the concrete. These formal and stereogeneous consequences are very distinct. (3)

HISTORY AND DEVELOPMENT

The history and development of fabric formwork for concrete, which is outlined in the following, begins at the turn of the twentieth century with a formwork patent for concrete. The development and applications of formwork principles have general or specific purposes. In the outline presented here, the history of fabric formwork is divided into three overlapping periods.

The technical development of fabric formwork in the early period, which lasts from around 1890 until the years just after the World War I, revolves around the use of organic fabrics with the purpose of simplifying construction methods. The middle period, from around 1960 to

1990, is characterized by the introduction of synthetic fibers such as polyolefin and polyester. The focus during this phase is on the use of fabrics to rationalize construction methods (ethical ambitions), fabrics manufactured as industrial products (commercial ambitions), and fabrics used to achieve a sculptural expression of concrete (artistic ambitions).In the latest period of development, since the 1990s, a focus on building components as part of construction systems has come to supplement the focus on ethical, commercial and artistic aspects. The informative timetable on the previous page by Veenendal et al, provide the types of development and the relationship between stages of developments of fabric formwork. (4)

Early development

The earliest appearance of fabric formwork for concrete pours is attributed[7] to the German architect, builder and inventor Gustav Lilienthal (1849-1933), who in 1899 patented a system for a fireproof ceiling,[8] in which structural beams used for building support suspended fabrics as formwork.[9]

The Australian-Irish engineer James Hardress de Warenne Waller (1884-1968) filed a number of patents for fabric formwork systems. (See illustrations on the next spread)
Waller worked for the Royal Engineers in Greece during World War II. Here soldiers used cement mix and slurry to camouflage tents and strengthen the canvas. This inspired Waller to develop the Nofrango[10] system, which was patented in 1934;[11] in the Nofrango system, wet hessian or a similar organic, woven fabric is stretched on a timber frame and plastered with cement mortar.[12] The tension conferred onto the hessian sheet is further increased when the fabric is wet, because the organic fibers contract under this condition.

The Nofrango technique exploits concrete in a fluid and solid state: A thin layer of concrete is applied to the textile falsework, causing it to deflect and create a structural surface. When hardened, this textile-reinforced concrete structure functions as falsework for additional layers of mortar. The first set of procedures expands the role of hessian as structure,[13] as the textile also helps to shape the concrete surface structurally. These principles governing these procedures can be categorized into four distinct types according to the structural role of the fabric (partly illustrated the next page):[14]

- Draped (stretched in one direction) and plastered (floor, roof)
- Stretched and plastered (wall)
- Filled and stressed through hydraulic pressure (column)
- Level, placed on the ground (ground floor, liners)

Waller used the principles at play in the Nofrango system to construct shapes inspired by his visit to the Great Arch of Ctesiphon in Iraq.[15] His patented Ctesiphon technique[16] is a combination of the general Nofrango construction method with a specific temporary supporting framework system based on inverted catenary 'ribs.'[17]

Waller worked closely with the German engineer Kurt Billig, who described the structural advancements of the Ctesiphon structure by comparing its arch properties to the properties of a conventional arch and its shell properties to the properties of a conventional shell. In terms of its arch properties, the catenary curve of the Ctesiphon Arch has significantly reduced weight, and as a shell it has greater rigidity due to its corrugations.[18] Between the 1940s and 1970s, different forms of the Ctesiphon system were employed for housing, storage and factories around the world.[19]

7 Veenendaal, West, and Block, "History and Overview of Fabric Formwork," 165..

8 Peter Collins, *Concrete*, 53–54. The fireproof qualities of concrete were seen as a crucial technical property to promote the use of the material, for example in the construction of theaters.

9 Otto Lilienthal Museum, "The Other Lilienthal: The Multi-faceted Life of Gustav Lilienthal (1849 – 1933) - the Younger Brother of Otto Lilienthal", 2006, http://www.lilienthal-museum.de/olma/egustav.htm. (Accessed 4-11-2011).The first patent for fabric formwork is tied to parallel inventions of tensioning textiles in the development of aviation technologies. Gustav worked closely together with his brother Otto Lilienthal (1848-96). Otto became the first successful aviator in history and also founded the science of wing aerodynamics.

10 Ciarán Conlon, "The Innovations and Influence of Irish Engineer James Hardress De Warenne Waller (Draft)" (BA Architecture, University College Dublin, 2011), 15. Conlon explains that the word Nofrango is loosely associated with the phrase "I will not break."

11 James Hardress de Warenne Waller, "Method of Building with Cementitious Material Applied to Vegetable Fabrics" (U.S. Pat. 1955716, 1934).

12 Ibid.; James Hardress de Warenne Waller, "Method of Constructing Canals and the Like" (U.S. Pat. 2015771, 1935).

13 David Harrison, "Dramatic Plasterwork: Fibrous Plaster in Theatres," *Building Conservation*, 2011, http://www.buildingconservation.com/articles/theatre/theatre.htm. (Accessed 22-11-2011).

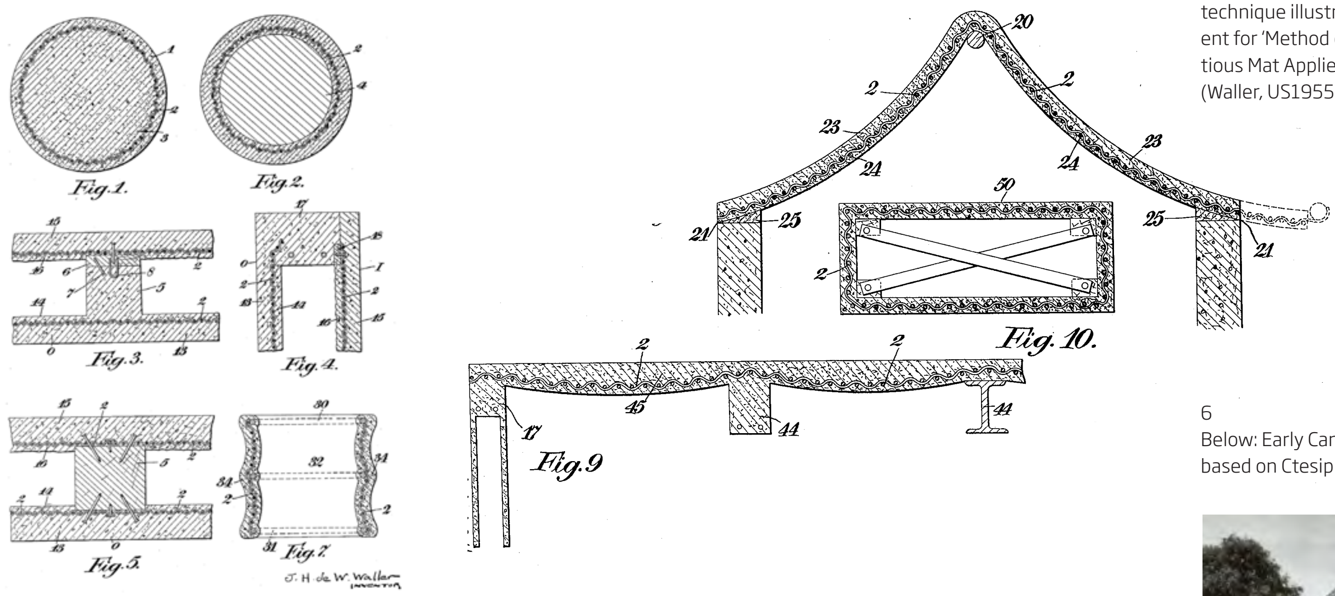
14 Veenendaal, West, and Block, "History and Overview of Fabric Formwork," 165–6. When reinforcing various plastered surfaces, an ancient technique

15 Conlon, "Waller," 15..

16 James Hardress de Warenne Waller, "Method of Molding In Situ Concrete Arched Structures" (U.S. Pat. 2616149, 1952). Built by Persian King Chosroes I between 531 and 579 C.E. The structure, consisting of mud bricks, lightly burned and set in Tigris mud, impressed Waller, who visited Iraq in 1922

17 Conlon, "Waller," 37. Rapid improvements of the Ctesiphon system sprang from Waller's partnership with the German engineer Kurt Billig, who was an expert on reinforced concrete.

18 Ibid., 95. Conlon cites a 1960 paper by Kurt Billig where he describes the benefits of the construction system.

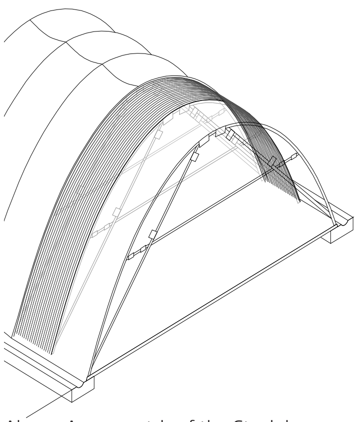


5
Different applications of the Nofrango technique illustrated in Waller's 1934 patent for 'Method of Building with Cementitious Mat Applied to Vegetable Fabrics' (Waller, US1955716)

6
Below: Early Candela Shell experiment based on Ctesiphon construction (Faber).

7
Top: Double curved brick vault, Dieste 1974. Below: Church of San Juan De Ávila, Dieste 1993-98

Above: The catenary-shaped Great Arch of Ctesiphon (Encyclopædia Britannica)



Above: Axonometric of the Ctesiphon construction principle (Reproduced from Conlon)
Below: Single span Ctesiphon shell under construction (Conlon)

Below: Plasterer applying finishing touches of the Nofrango method to Ctesiphon shell construction.

Waller and Billig's achievements are interesting, because they combine a general and simple construction method for applying thin layers of concrete with a group of techniques for building specific funicular shapes. This experimental work inspires the coming generation of shell builders. The Spanish engineer Felix Candela (1910-1997) used the method to build his first experimental shell in Mexico in 1949.[20] As he developed different, mathematically based geometries he soon moved on to different methods of construction. (6)

Candela's early investigations of the Ctesiphon principles can be compared with the focus of the Uruguayan engineer and architect Eladio Dieste (1917-2000), who undertook formal explorations of surfaces in order to solve structural problems.[21] (7) Even if Eladio Dieste did not use fabric formwork for any of his structures but instead relied on reinforced brick masonry, his reinforced brick shells can be described as a textile building approach, in the sense that the bricks are bonded to each other as a woven surface[22] and 'threaded' and shaped by reinforcing rods. Thus, the comparison emphasizes the textile principles of weaving and binding the reinforcement structure, which Dieste developed further, and Candela abandoned.

Fabric formwork 1960-1990

The period between the first commercial availability of synthetic fibers in the 1950s and the development of fabric formwork in the 1990's was characterized by the pursuit of commercial purposes, aims of developing rational construction techniques, and artistic aims of expressing the original state of wet concrete by sculptural means.

Business

The commercial development of fabric formwork from around 1960 included the improvement of geotechnical textile systems for lightweight, collapsible fabric formwork patents described as mattress systems[23] to secure embankments and shorelines.[24] These mattress systems, illuatrated to the left, can also be described by means of their resemblance with the plastic bags used to make ice cubes. Another group of products, illustrated right, includes so-called pile jackets for the renovation of offshore concrete piles. Some of these systems complete the metaphor and practice of tailoring with the use of a zipper as an on-site closing device.[25] (8 and 20)

Pneumatic Formwork

In the 1960's, the new plastic membranes made it possible to tailor-make large balloons and membranes as pneumatically inflated concrete falsework for the automated construction of concrete domes.

In 1964, the Italian architect Dante Bini (b. 1932) initiated experimental work including the Bini Dome Construction Automation System.[26] The illustrations a few pages back show the principle, in which involves pouring concrete on the flat, deflated structure and subsequently inflating it, as the pressure of the wet concrete begins to decrease, but before the concrete has fully cured. Bini exploits the fluidity in construction, i.e. the series of conditions that occur when flexible membranes become rigid, and concrete goes from liquid to solid. The flexibility of membrane formwork allows it to be inflated uniformly after the concrete pour to become rigid. It simplifies the pour, because the concrete can be applied to a flat surface and subsequently inflated to take on a particular shape.

The Binix prototype[27] is another variation of the Bini shell. Here prefabricated concrete elements are placed on the flat membrane before inflation. The system thus further exploits

19 Veenendaal, West, and Block, "History and Overview of Fabric Formwork," 166. Such as the UK, Ireland, Zaire, Zimbabwe, Tanzania, Nigeria, Kenya, Australia, Spain, Greece, and India.

20 Colin Faber, *Candela, the Shell Builder* (Reinhold Pub. Corp., 1963), 17..

21 Stanford Anderson, "Eladio Dieste, a Principal Builder," in *Seven Structural Engineers: The Felix Candela Lectures*, ed. Guy Nordenson and Terence Riley (The Museum of Modern Art, 2008), 38..

22 Gottfried Semper combines his theory of textile origins with his concept of stereometry to categorize brick facades as woven. Techniques applied by Dieste, of 'laminating' brick and mortar, resemble modern production of high performance sails such as 3DL by North Sails.

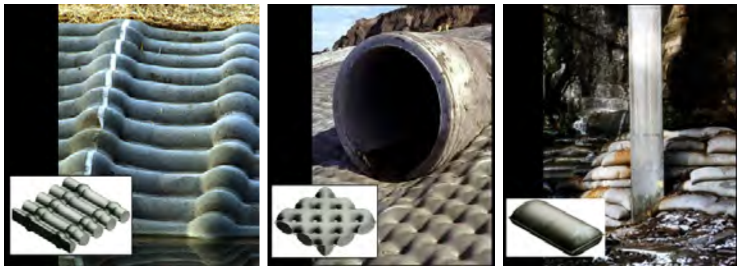
23 Hakim Abdelgader, Mark West, and Jaroslaw Gorski, "State-of-the-Art Report on Fabric Formwork," in *ICCBT 2008* (presented at the International Conference on Construction and Building Technology 2008, Malaysia, 2008), pp 93-106..

24 Examples of commercial products: Hydrotex, "Hydrotex Fabric Forms", 2006, http://www.hydrotex.com/; "Construction Techniques | Fabriform® Fabric Formed Concrete System", 2010, http://www.fabriform1.com/pilejacketinstallation.html; Brennan, "Erosion and Scour Control - Fabric Form System", n.d., http://www.jfbrennan.com/erosionscourcontrolfabric.html. Veenendaal, West, and Block, "History and Overview of Fabric Formwork," 168. Veenendaal et al write the prior to the use of polyolefines as concrete formwork mattresses, burlap systems were in use; prior to the use of concrete, these mattresses or bags were filled with sand and rocks.

25 TOPCOR Companies, "Pile Jackets", 2010, http://www.topcor.com/restoration.html. As an example.

Left: Pile-jackets (Fabriform1.com).

Below: Revetment protection systems (Hydrotex)



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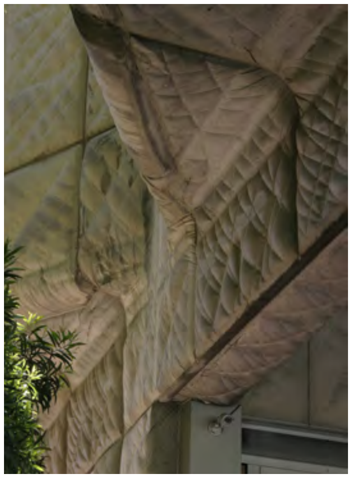
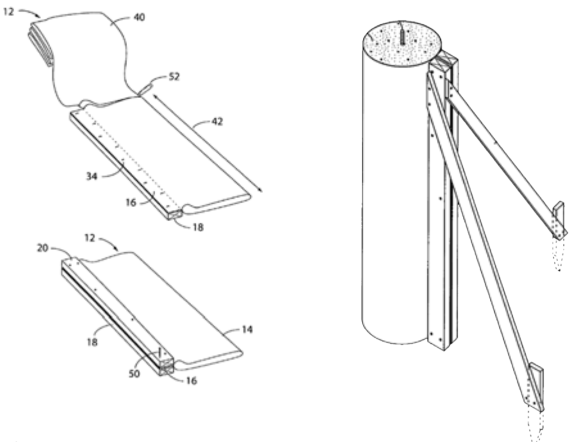


9
Facade panels dress all outer surfaces of a rehabilitation center in Madrid (1969) Miguel Fisac. Photos by AMM.



10
Fast-Tube™ column formwork by Fab-Form Industries, Rick Fearn.

26 Dante Bini, "BINISYSTEMS, Construction Automation", 2009, http://www.binisystems.com/construction_part1.html. (Accessed 16-11-2011) Bini conducted his first full-scale experiment with automated construction in New York, 1964.

27 Ibid.

28 Introduced in the Concrete/Concreting chapter

29 Richard N. Fearn, "Building Foundation and Floor Assembly" (U.S Pat. 5224321, 1993).

30 Richard Fearn, "Fab-Form, Fabric-Formed Concrete," Company Website, *Fastfoot Industries Ltd*, n.d., http://www.fab-form.com/. Fearn lectured at the ICFF2008. "International Conference on Fabric Formwork 2008", May 2008, http://www.umanitoba.ca/faculties/architecture/cast/conference/index.html..

31 Mark West, "Kenzo Unno : Fabric-Formed Walls" (CAST, University of Manitoba, October 11, 2007), 2, http://www.umanitoba.ca/cast_building/assets/downloads/PDFS/Fabric_Formwork/Kenzo_Unno_Article.pdf..

32 Kenzo Unno, "Lecture by Kenzo Unno," in *Fabric Formwork Conference Speakers* (presented at the First International Conference on Fabric Formwork, Winnipeg, Manitoba, Canada: CAST, University of Manitoba, 2008), http://www.arch.umanitoba.ca/cast/2.kenzounno/. and West, "Kenzo Unno.". The Japanese architect Shigeru Ban developed a simple construction system using paper column formwork tubes for building shelters and temporary community spaces. Unno's concern was to reestablish permanent homes.

33 West, "Kenzo Unno.".

34 West, "Kenzo Unno," 3.

Unno Reinforced Concrete, Kenzo Unno, Japan
Left: quilt-point method. Photo Tsunenori Yamashita.
Right: frame method. (West 2007)

11

states ranging between liquid and solid in its combination of elements from Luigi Nervi's structural prefabrication method[28] with the use of pneumatic falsework.

Sculptural surfaces

Work by the Spanish architect Miguel Fisac was introduced in the concrete chapter and illustrated further on the previous page. Fisac used the flexibility of the new plastic membranes as a formwork material to express the liquid original state of concrete. (9)

RECENT DEVELOPMENTS

The three strands of development discussed so far, driven as they are by commercial purposes, construction and sculptural artistic practices, continue in the 1990s, now aimed at specific construction purposes. Three people work in parallel and independently: the Canadian builder Richard Fearn, the Japanese architect-builder Kenzo Unno, and the American artist, architect and builder Mark West.

Rick Fearn (Commercial Purposes)

Geotechnical formwork systems entered the building construction industry with the Canadian builder Richard Fearn.[29] With his company Fab-Form Industries, Fearn introduced a series of systems for prefabricated fabric formwork for columns (illustrated right), foundation liners, and point foundations for buildings and walls.[30] (10)

Kenzo Unno (Construction)

Ever since the devastating earthquake in Kobe in 1995, Japanese architect and builder Kenzo Unno has aimed to develop simple construction systems that allow people to construct their own robust homes.[31] 'Unno Reinforced Concrete' (URC) is a formwork system for the simple construction of monolithic concrete walls cast in fabric forms. Since the first walls cast in scaffolding nets were constructed in 1998, variations of the URC technique have been used to build a small number of houses in Japan.[32]

Quilt and frame

Two variants of the URC system have been described from the point of view of the method used to restrain the formwork membrane: the *quilt-point method* and the *frame method*.[33] (11)

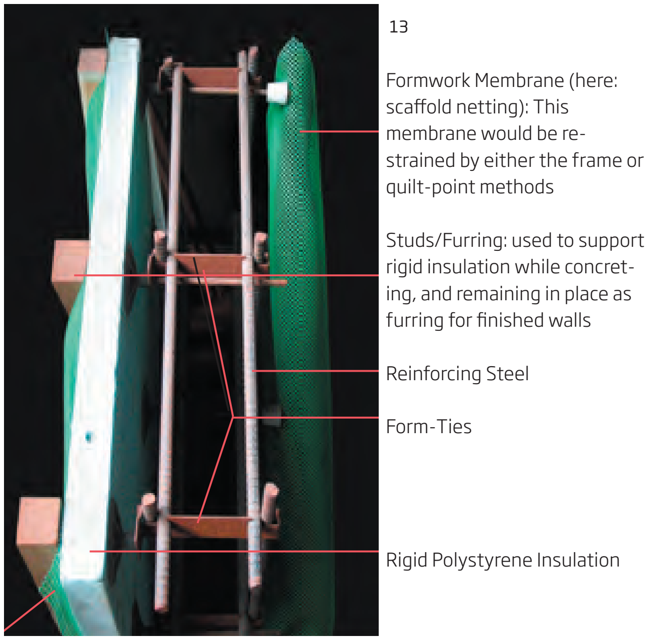
The URC quilt-point method illustrated in the right image is a restraining method defined by a gridded pattern of form ties where flat, round metal washers restrain the formwork membrane. In the URC frame method illustrated in the left image, the flexible formwork membrane is restrained by linear frame elements such as wooden studs or steel pipes, which are held in place either by external bracing or by standard form ties.[34] The rigid frame elements restrain a larger surface than a point restraint, and as a consequence the frame method requires fewer ties than the quilt-point method.

The URC system has been used to construct monolithic structures in Japan, and it has inspired other builders, including the American architect-builder Sandy Lawton of Arro Design, Vermont, USA. (12)

12

Right; Illustration of Kenzo Unno's Zero-Waste Formwork , a combination of fabric and stay-in-place insulation board. (West,2007)

13



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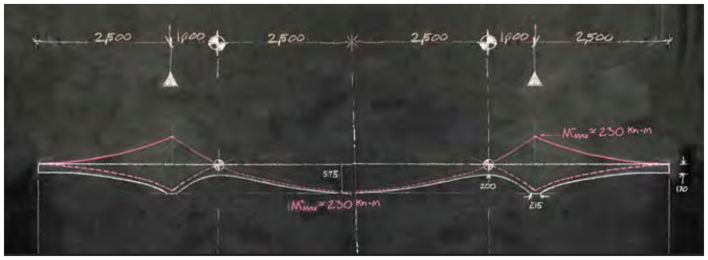


Top: Schultz House, Vermont, USA. Below: frame system ready for pour - notice silvery formwork tubes by Fab-Form, ready to cast columns. Right: Stripping the formwork. Arro Design, 2008.

Above: Images of Hanil Visitors Center & Guest House, South Korea, by Byoung Soo Cho Architects (2008-09). CAST developed the formwork principle, Images from CAST web site.

Right, work at the Center for Architectural Structures and Technology (CAST). The top three images show the construction of the Bone Beam discussed on the next page.

Insulation as rigid formwork

An application of the URC quilt-point method uses the reinforcement steel of the wall to keep the formwork membrane separate from the interior, so that no exterior framing members are needed.[35] Another variation is the formwork system that uses commercially available rigid insulation boards as permanent formwork on one side of the formwork structure and fabric netting on the other side. The bracing studs backing the insulation boards can later be used to mount exterior façade cladding or interior plasterboards. (13)

This example of Unno's simplified approach to construction is basically a "Zero-Waste" system. In order to improve sustainability in construction, it is necessary to develop methods for minimizing waste and the CO_2 footprint. Although sustainability lies outside the scope of the present thesis, this ambition of *minimizing* waste is nevertheless relevant, although it is treated from an architecturally enabling perspective here as an ambition of *optimizing* construction processes and materials.

Further construction

A few built examples include the façade for a visitor center for the South Korean cement company Hanil (14). The project is designed by Byoung Soo Cho Architects (2008-09) and applied a formwork principle for the two storey tilt-up façade elements devised by CAST.[36] Architecture students from the University of Edinburgh and the University of East London have applied a similar principle for a landscape and gardening exhibition.[37]

Mark West (Artistic practice)

The American professor, architect and builder Mark West is the pioneer of contemporary fabric formwork. West's explorations began in the 1980s, and his early efforts included teaching architecture students[38] and an exhibition at the Storefront for Art and Architecture in 1992.[39] In 2002 he founded CAST (Centre for Architectural Structures and Technology) at the University of Manitoba in Winnipeg, Canada. CAST is the first and, so far, the only laboratory specifically built to accommodate research in fabric formwork.

The laboratory facilitates practices ranging from various modes of drawing and model making to 1:1 concrete prototypes and scientific test equipment. A preoccupation with textile properties in relation to concrete has been a consistent theme in the center's research into beams, columns, walls, slabs, and shell structures.

The work at CAST springs from a fascination with expressing the original liquid state of concrete in a structural form. The formal expression of the cured liquids poured into flexible membranes evokes different emotions and challenges aesthetic judgment. In her essay "Fabric Formwork – the Beautiful, the Sublime and the Ugly,"[40] the Canadian architect Ilona Hay interprets elements of the aesthetic classification system developed by the 18th-century Irish statesman and author Edmund Burke. [41] Burke developed a British aesthetic theory that included sensations of the beautiful as well as the sublime seen as a terrifying counterpart of the beautiful.[42] Burke originally identified qualities as variation, texture, size, delicacy and, light to define aesthetics. Hay applies these parameters to a reading of fabric formed objects to discuss the aesthetics of the construction method.[43]

Hay describes West's early body of work (15) as ranging from the ugly to the beautiful and the sublime.[44] She views structural forms such as West's Bone Beams as beautiful, and highly

35 West, "Kenzo Unno," 3. Kenzo Unno, *Residence for Client Katsunori Hiyoshi*, Architecture, House, 2002, Koutou-Ku, Tokyo, Japan.

36 Mark CAST, "CAST :: Research", 2010, http://www.umanitoba.ca/faculties/architecture/cast/research/index.html.

37 The system was designed by Professor Remo Pedreschi Remo Pedreschi and Alan Chandler, "Concrete Panels: The 2009 Chelsea Flower Show", May 2009, http://roar.uel.ac.uk/jspui/handle/10552/1122.

38 Mark West, "Fabric-Formed Concrete Structures" (CAST, University of Manitoba, March 20, 2002), note 2, http://www.umanitoba.ca/cast_building/resources.html. Columns cast with students at Carleton University, Ottawa, Ontario, Canada, 1989.

39 Mark West, *Chalmers Lecture About Fabric Formwork*, Sound (Gothenburgh, Sweden: Recorded by AMM, November 2009).

40 Ilona Hay, "Fabric Formwork - the Beautiful, the Sublime and the Ugly," in *Fabric Formwork*, ed. Alan Chandler and Remo Pedreschi (RIBA Publishing, 2007), 59-75..

41 Ibid., 61. Hay refers to "A Philosophical Enquiry into the Origin of our Ideas of the Sublime and the Beautiful", published in 1757.

42 Harry Francis Mallgrave, *An Anthology from Vitruvius to 1870* (Wiley-Blackwell, 2005), 249–250., cited in Hay, "Beautiful Sublime Ugly," 61..

43 Alan Chandler and Remo Pedreschi, eds., *Fabric Formwork* (RIBA Publishing, 2007), 71..

44 Hay, "Beautiful Sublime Ugly," 59..

45 Ibid. Hay describes *ugly* as an aesthetic category and compares the aesthetic extremes of West's work as examples of the Burkeian beautiful and sublime. "*In terms of aesthetic appreciation, there seems to be a threshold between the extremes, a point at which one may cease to admire and appreciate, and instead be awed, or even be disturbed or repulsed.*"

46 Ibid., 60..

47 Katie Lloyd Thomas, "Matter and Form in the Making of Wall One," in *Fabric Formwork*, ed. Alan Chandler and Remo Pedreschi (RIBA Publishing, 2007), 45-57. For example in the participation of Mark West in workshops such as the one that produced Wall One, 2004 and initiated the research programme between UEL and ESALA.

48 The website is a compilation of aesthetically pleasing photographs, documented construction methods, references to published papers, and built work. CAST, "CAST :: Research.".

sculptural objects, such as the Carleton Bulge, as disturbing and ugly.[45] She also points out the difference between work created before and after the establishment of CAST; the results of West's sculptural practice prior to CAST are *"more mannered and sloppy – extreme in form variation. This probably indicates less precise control over the process, prior to using industrial methods."* [46]

It is relevant to discuss the aesthetics of fabric-formed. In the architectural research in the present dissertation, it is however difficult to carry out a critical architectural discussion of the concrete objects created by Mark West without including two crucial parameters, namely the intended purpose of the different architectural investigations and their context.

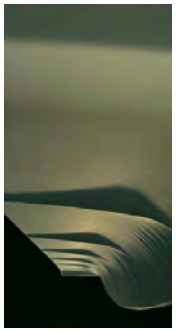
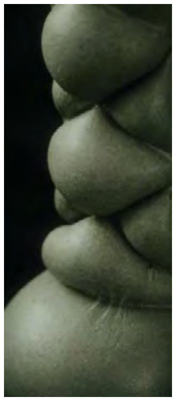
The purposes of the former range from the general-formal to the specific-structural. Early sculptural work by West and students can be described as general-formal investigations of materials and methods through making. The results are sculptural and may please or displease, but the investigation of the elements, materials and procedures of construction occurs through the practice of making. The context for the sculptural practice includes temporary workshops and exhibitions

West's later work at CAST, illustrated on the previous spread, contains additional architectural layers and is not solely driven by a fascination with the possibility of casting varieties of bulging, liquid rocks, so to speak. The context of the later work is research through the making of prototypes. Fabric-formed concrete slabs and columns do combine sculptural exploration of forms and surfaces with the structural types of columns and tilt-up wall elements. But prototypes built of fabric-formed beams and shells rather expand on the structural use and behavior of the formwork fabrics and the structural potentials of the concrete structures. This work can be described as aimed at specific architectural investigations into structural form and process using a variety of fabrics and procedures of concreting. (16)

The general and specific architectural (re)search aims and methodologies at CAST investigate the elements of making, forming, shaping, and molding matter. This curiosity, which is directed at deriving new techniques, forms, and structures from well-known materials, reflects the essence of architectural studies and has been a source of inspiration to universities and art academies throughout the world. The work at CAST is communicated through a practice of lecturing and teaching within and outside the University of Manitoba [47] as well as CAST's comprehensive and informative website.[48]

The images on the previous spread and to the right illustrate research conducted at CAST of form-optimized beams and trusses cast in flat sheets of fabrics. [49] The chalk drawing show the shape of the bending moments that correspond with the fabric-formed element.This work has led to additional research into construction methods and behaviors of reinforced form-optimized concrete beams at the University of Manitoba[51] and inspired to work at technical universities in Europe, including the University of Bath Department of Architecture and Civil Engineering,the Edinburgh School of Architecture and Landscape Architecture in the United Kingdom, and the Block Research Group at ETH in Zürich, Switzerland.

This work can be categorized as specific scientific research into the production and structural behavior of prefabricated, form-optimized concrete beams. Research at the Block Research Group includes a PhD project[53] that focuses on the scientific development of computer-based tools for designing, simulating, and dimensioning fabric formwork and fabric-formed structures.

15

'Bone Beam' and the sculpted 'Carleton Bulge' by Mark West (Reproduced from Hay, 59)

16 Truss and impacto formwork made at CAST (CAST)

49 Initial work at CAST 2002-2006. A beam is a structural element that is capable of supporting a load primarily by resisting bending.

51 PhD project at the University of Manitoba: PhD engineering candidate Fariborz Hashemian's dissertation on the Structural Behavior of Variable Section Beams; Master's project at the University of Manitoba: Farhood Delijani, Master's Thesis on Strength Gains in Concrete Cast in Permeable Fabric Molds.

Fig. 17.Fabric-formed art installation by Ernesto Neto

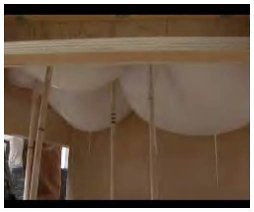


Fig. 18. P_Wall (MoMA San Fransisco) and image of the making of the plaster elements, Andrew Kudless (Kudless 2009)

ARTISTS

A few contemporary artists are worth mentioning for their work regarding textile as formwork.

The Brazilian visual artist Ernesto Neto (b 1964) makes site-specific installation and uses textiles as suspended, filled structures, as illustrated in fig. 17. The structure exploits tensile and spatial elements of textiles and uses a variety of dry, powdered materials and spices as 'invisible' yet tangible and sensible materials.[54] The relation between the suspended fabric forms and the material that fills them, and the viewer, remains open for negotiation. The textiles are present in the sculptural installation and they display a playful approach to the concept of suspending and filling textile forms and suspending soft floors or translucent ceilings.[55]

The architect Andrew Kudless of the California-based architect office Matsys (Material Systems) works with digital fabrication processes. However, he has found inspiration from the flexible formwork developed by Miguel Fisac for a series of plaster wall. The P_Walls[56] are plaster cast in elastic nylon fabrics and restrained by wooden dowels, shown on the right. The works display an investigation of the relationships between two flexible materials and their interrelated consequences when constrained.[57] (18)

CONSTRUCTION PRINCIPLES

The final section of the introduction to fabric formwork offers an introduction to the principles of construction. The construction methods for fabric formwork can be briefly described as the application of concrete, textile types, and principles and the formwork boundary conditions.
A number of principles are listed in the following or illustrated in 'Taxonomy of fabric formwork and formwork liners'.[58] (19)

Concreting procedures used for fabric forming

Different structural principles to enable textile to support concrete require different properties in the concrete mix and in the casting procedure.
The following is an introduction to casting procedures for poured (or filled) concrete and thin-layered concrete.[59]

1. *Pouring* concrete into formwork or mold
    a. For larger pours,[60] concrete is delivered from a factory by truck and either dropped from a conveyor belt or delivered in a more controlled manner via a pump.
    b. For small pours[61] or very slow pours, the maker can mix the concrete on site.
2. Application of concrete in thin layers
    c. *Spraying*[62] from a nozzle on vertical surfaces or application as self-compacting concrete on a horizontal surface.
    d. Rendering or hand-*padding* of fiber-reinforced mortar for controlled thinness.[63]

53 Diederik Veenendaal, "PhD Project", December 29, 2011. PhD project by the Dutch structural engineer Diederik Veenendal "Informed Design of Fabric Formed Structural Systems." The project is inspired by computational and analytical practices concerning tensioned membrane and cable-net roofs.

54 Ernesto Neto, *The Malmö Experience*, Installation, The main gallery hall, May 18, 2006, Malmö Kunsthall, Sweden, http://www.konsthall.malmo.se/o.o.i.s?id=3234. Filling materials include, cotton, EPS pellets, sand, and different spices, as recalled from visiting The Malmö Experience.

55 ibid.

56 Andrew Kudless, "P_Wall(2006) « MATSYS", n.d., http://matsysdesign.com/category/projects/p_wall2006/. P_Wall 2006, installation at the Banvard Gallery, Knowlton School of Architecture, Ohio State University, Columbus, Ohio, and P_Wall 2009, commisioned for the Museum of Modern Art in San Francisco, California, USA.

57 Ibid.

58 Veenendaal, West, and Block, "History and Overview of Fabric Formwork," 174.

59 Ibid., fig. 29..

60 Of consecutive pours of over 2-500 liters and for uniform mixing properties.

61 Less than a few hundred liters.

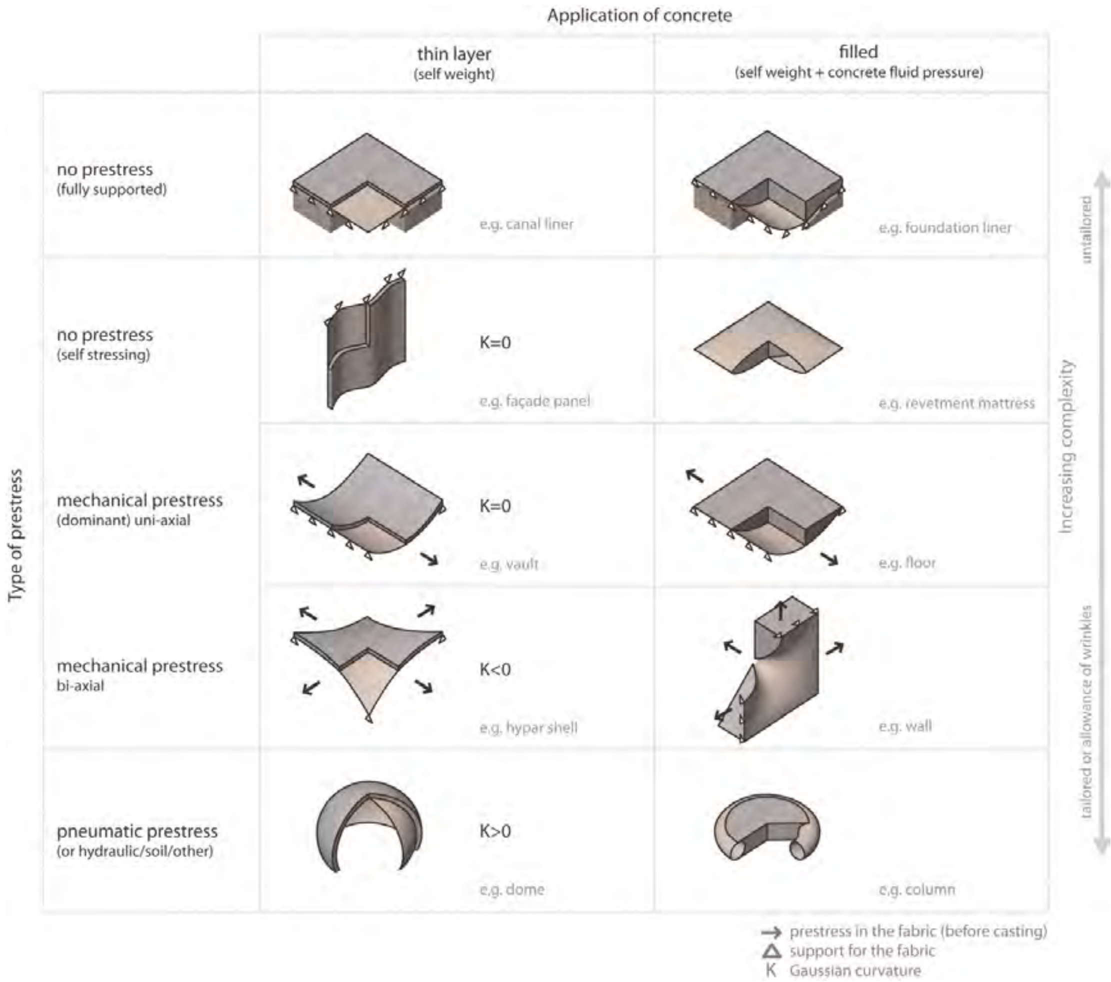


Fig. 19. Taxonomy of fabric formwork and formwork liners (Reproduced from Veenendaal et al)

20
Fabric tensioned by selfstressing - or 'Hung' formwork. Illustrations of installations of off shore pile jackets, reproduced from brochure (Fabriform1.com)

Columns cast in tensioned fabric formwork for the construction of Casa Dent by Cheng Design [66]

TEXTILE PRINCIPLES

The term textile principles refer to the properties of the selected textile used as formwork as well as the method used to tension the textile. The possible properties are too numerous to list here, but include high elasticity of textiles used for the sculptural work at the Storefront for Art and Architecture as well as the stiffer, woven character of polypropylene of high tensile strength used in the construction of prototypes for beams, columns and walls.

Since textile 'acts' and deflects in tension, the principle used for tensioning the fabric has considerable stereogeneous significance. Three categories of prestressing describe principles of tensioning formwork membranes as illustrated in figure 19 on the previous page.[64]

- The first category has no prestressing when the textile is fully supported and acts as functional membrane liner.
- The second category of formwork textiles is mechanically prestressed. This category includes textiles that are only prestressed by their own weight from hanging, textiles that are tensioned in one direction, and textiles that are tensioned in more than one direction.
- The last category of formwork textiles is prestressed by means of pneumatics (inflated formwork).[65]

BOUNDARY CONDITION

The boundary condition for fabric formwork establishes the tensioned fabric. It may be simple, for example the rigid joint of a fabric tube used as column formwork, or more complex, such as an external frame, cage or other lateral restraints. "*In every case the fabric will always assume a pure tension geometry between whatever boundary conditions are set by the formwork design*."[67]

Frame and rig

In the present dissertation, the boundary condition is described as a frame and rig, signifying equipment for a particular purpose.[68] Furthermore, restraining systems that technically belong to the boundary condition are described independently as clamps, form ties or other, similar devices. Technically, the frame is the textile suspension devise. This entails the conceptually linked opposition of releasing form.

Form tie and impacto

The elements that Kenzo Unno uses in his frame restraint method may be described as large, linear washers that connect form tie points on a surface. The term impacto[69] describes the disks that face the formwork membrane. The shape of the form tie element known as an impacto creates an impact on the concrete surface, similar to a stamp. (11)

Conceptually, restraining principles for vertical pours are ways of 'tying form.' The conceptual aspect indicates the fluid origins of concrete that can be formed through restraints. Literal explorations of the concept include the 'flexible formwork' system developed by the Spanish architect Miguel Fisac[70] and the sculptural practice by the American architect, artist, and builder Mark West. This sculptural work can be categorized as explorations of conceptually 'softening' concrete as solid mass.

	Construction	Architectural (Re)search	Scientific Research	Artistic Practice
General	Enabling the construction of cheap and sturdy structures for housing	Sculptural form and technique through making and 'creative play'	Development of digital tools for design, simulate, and dimension fabric formwork and fabric formed structures	Expression of liquid origins of concrete and conceptually 'softening' concrete Expression of procedures. i.e. material dialogue, restraint, relaxation
Specific	Standardized formwork products for the construction of columns and foundations	Specific architectural investigations into structural form and process using a variety of fabrics and procedures of concreting	Production and structural behavior of prefabricated, form-optimized concrete beams	Voluptuous wall panels and columns

Above, the table classifies general and specific aims in four practices of fabric-formwork

Summary

The table above summarizes general and specific aspects of the development of practice and research in fabric formwork.

The past chapters about concrete and concreting, stereogeneous construction, textiles in construction and fabric formwork for concrete has established and investigated the practice in these past chapters, practical investigations into formwork tectonics and stereogeneity have focused on the relation between concrete and procedures of construction, textile notions and principles in concrete construction as well as a family of textile construction. Finally the development and principles of fabric formwork have been introduced. Key figures in the past decades' development of fabric formwork have explored the relation between fabric molds and concrete as either a commercial/technical approach to procedures of construction, an ethical practice of construction, or a sculptural, artistic practice. Since the establishment of CAST in 2002, however, the latter aspects begin to overlap.

62 "ACI Shotcrete Nozzleman Programs : Shotcrete Nozzleman (Wet-Mix Process)," *American Concrete Institute*, n.d., http://www.concrete.org/certification/Cert_pgminfo.asp?pgm=Shotcrete+Nozzleman+(Wet-Mix+Process).Spraying concrete belongs under the common category called shotcrete. It can be applied as a dry or wet process by a Shotcrete Nozzleman, a great term certified by the American Concrete Institute.

63 At CAST, concrete applied in this manner is nicknamed 'cow shit' due to its fibrous, muddy consistency. The procedure is used in experiments and prototypes, but West suggests the use of spraying for industrial use, in *Heavy Light - Fabric-Formed Concrete Structures* (ETH, Zürich, Switzerland: Institute of Technology in Architecture, Building Structure, 2011), http://www.youtube.com/watch?v=36gOx3dguWs&feature=youtube_gdata_player..

64 Veenendaal, West, and Block, "History and Overview of Fabric Formwork," 174.

65 The taxonomy also mentions soil and hydrostatic pressure, but these have been left out here.

66 Mark West, "Fabric-Formed Concrete Columns for Casa Dent in Puerto Rico" (CAST, University of Manitoba, October 10, 2002). www.umanitoba.ca/cast_building/resources.html. (Accessed 12-11-2011). For the American architect Fu-Tung Cheng of Cheng Design.

67 Abdelgader, West, and Gorski, "SoA Fabric Formwork," 97.

68 *The Cassell Compact Dictionary* (London: Cassell, 1998), Rig, –n.2..

69 A term developed at CAST, used for example by Mark West in a lecture at RDAFA, September 2007.

70 His work is introduced in Concrete and Concreting

4/ ANALYTICAL INVESTIGATION

INTRODUCTION TO ANALYTICAL INVESTIGATION

DOCUMENTATION AND COMPARISON

PRESENTATION OF ANALYTICAL CASES

ANALYTICAL STUDIES OF THE FRAME

ANALYTICAL STUDIES OF THE FORM TIE

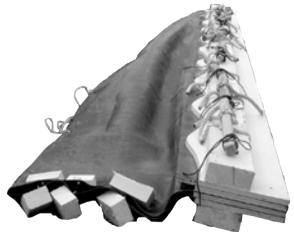
ANALYTICAL STUDIES OF THE TEXTILE

CALENDAR OF EXPERIMENTAL DATA

Workshops and *keywords*
Numbers refer to the section in the appendix

Reference to analytical case studies

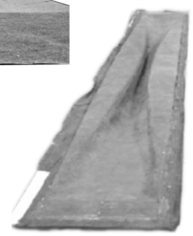
2007
Sep <3△ [3] — 1 CAST at RDAFASA *
Simple means/formal consequence



Oct
Nov
Dec

2008
Jan
Feb
Mar
Apr
May — [First International Conference on Fabric Forming (ICFF2008), CAST, Winnipeg]

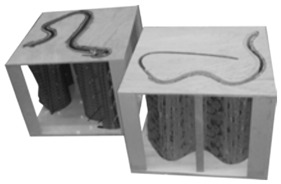
Jun
Jul
PhD Starts **Aug**
Sep
Oct — [Visit to ESALA, Edinburgh]



Nov
Dec

2009
Jan
Feb 65▲▲ [10] — 2 TEK1/ Sharp / soft
Flexibility / Restraint

Mar ▲ [2] — 3 Ambiguous Chairs
Context/Quilt point method

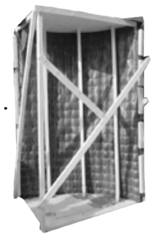


Apr
May
Jun 12△ [1] — 4 Vermont Wall **
Full-scale/Quilt-point method

Jul
Aug
Sep
Oct
Nov 100△▲ [3]^ — 5 Concrete Flesh ***
No restraints

Dec

2010
Jan
Feb
Mar 70▲▲ [11] — 6 TEK1/ Walls
Textile / Restraint/ Frame (set dimensions)



Apr
May
Jun
Jul
Aug 35▲ [4] — 7 Concretum, Erasmus Summer School, Bornholm
Textile / Restraint/ Frame / Context

Sep
Oct
Nov
Dec

2011
Jan
Feb
Mar 80▲ [11] — 8 TEK1/ Benches
Textile / Restraint/ Frame / Context

▲80 Workshop organizer and number of participants
△80 Workshop participant and number of participants
Walls
Shells, vaults
Columns, arches
Sculptural objects
[5] Number of experiments
* Planned by CAST
** Planned by Sandy Lawton
*** Planned by Chalmers
^ Number of experiments by the author, not by all

INTRODUCTION TO ANALYTICAL INVESTIGATION

	Workshop / Experiment		Typology of concrete						Frame principle						Fabric principle			Restraint principle			Construction		Concreting				
			Column	Beam	Horizontal slab	Wall	Shell	Sculptural Object	Rigid back	Frame	Rig	Suspended	Hung	Embracing fabric	Embraced	Connect/hinge	Composite	Point	Net/Framing system	Other	Construction of formwork	Reinforcement	Vertical (V) or horizontal (H)	In situ or element	Concrete type	Role of the author	Student work
1	**Columns by CAST, RDAFASA 2007**								VL											Jacket	In Situ	Minimum	V	Situ	SCC (old)	Assistant	
	Sinus Column	1.1	x						x					x						x							
	Fab-Form Column	1.2	x						x					x						x							
	Voodoo Column	1.3	x						x					x						x							
2	**Workshop TEK1, 2009**																							In Situ	4-8 mm	Organizer	
	Clamp Wall	2.1				x				x								Sq			Pre	No	V	In Situ			x
	Hexagonal Cone	2.2	x						x		x	x				x					Pre	No	V	In Situ			x
	Geometrical Rotation	2.3	x						x						x						Pre	No	V	In Situ			x
	S-Mattress	2.4				x					x	x						Loop			Pre	No	V	In Situ			x
	Seal	2.5			x						x				x		X			Laths	Pre	No	V	Element			x
	Big C (Plywood/Bubble Wrap)	2.6				x			x					x		x				Rigid	Pre	No	V	In Situ			x
	Bench	2.7						x			x	x		x							Pre	No	H	In Situ		x	
	Grandma's Curtains	2.8	x						x									Seams			Pre	No	V	In Situ			x
	Ham Arch	2.9	x						x					x		x		Rope			Pre	No	V	In Situ			x
	Paper airplane	2.10						x	x														Hand	Element			
3	**Exhibition, Scandbuild Trade Fair, 2009**					(x)				x								Q			Pre	PVA		Prefab	ECC PVA	x	
	The Ambiguous Chair, S-shaped chair	3.1				(x)		x			x	x						Q					V				
	The Ambiguous Chair, ∂-shaped chair	3.2				(x)		x			x	x						Q									
4	**Wall in Vermont, ISOFF Workshop 2009**					x												Q			Semi	Carbon grid	v	In situ	8-16 mm	x	
5	**'Concrete Flesh', Workshop at Chalmers 2009**																										
	Chalmers Column	5.1	x								x		x		x						Prefab	No	V	In situ	Fibre 16mm	x	
	Two shells	5.2-3					x						x				xx				Prefab	GFRC	H	Prefab	Mortar frc (old)	x	
6	**Workshop TEK1 2010**																							In situ	4-8 mm liquid	Organizer	
	Twist wall	6.1				x				x					x				Laths		Prefab	Minimum	V	In situ			x
	Leaning Arch	6.2					x		Ply	x					x						Prefab	Minimum	V	In situ			x
	Wall de Mort (Net Wall)	6.3				x				x					x			x	Net		Prefab	Minimum	V	In situ			x
	Perforated Curved Wall / S Wall	6.4				x				x		x						Block out			Semi	Minimum	V	In situ			x
	Ham Wall	6.5				x			x						x				Rope		Prefab	Minimum	V	In situ			x
	The Illusion (Door)	6.6				x			x							x				Rigid	Prefab	Minimum	V	In situ			x
	Vastoin (Wood-Fabric Wall)	6.7				x			x						x			X			Semi	Minimum	V	In situ			x
	Chesterfield Wall (Butt Wall)	6.8				x			x						x			Inverse			Prefab	Minimum	V	In situ			x
	Paper Fold Wall	6.9				x			x												Prefab	Minimum	V	In situ			x
	Composite Column	6.10	x						VL					x			x		x	Jacket	Semi	Minimum	V	In situ		x	
7	**Concretum - Erasmus Material Culture, 2010**																										
	Bridge	7.1					x					x			x					Textile	Semi	x	Hand	In Situ		Organizer	x
	Bornholm Wall	7.2				x							x		x				Rebars		In Situ	x	V	In Situ			x
	Furniture units	7.3					x			x	x	x								Textile	Prefab	x	Hand	Prefab			x
	Wood	7.4						x	VL					x			x			Jacket	Prefab	x	V	Prefab			x
8	**TEK1 2011**																										
	Bench for Three	8.1	(x)					x	VL		x	x										x	H	Element			x
	Date Bench	8.2				(x)	x	x		x												x	V	Element			x
	G Bench	8.3				(x)		x	x													x	V	Element			x
	Copenhagen Bench	8.4						x	x													x	V	Element			x
	Kompakt	8.5				(x)		x	x													x	V	Element			x
	Rhombus	8.6			(x)			x		x	x	x										x	H	Element			x
	Ham (Rotation)	8.7				x	x	x		x												x	V	Element			x
	898 (Sofa)	8.8						x	x													x	H	Element			x
	Rope	8.9			(x)			x		x	x											x	H	Element			x
	Cloverleaf	8.10	(x)					x		x												x	V	Element			x
	Tongue	8.11					x	x	x		x											x	H	Element			x
	Crushed Wave	8.12				(x)	x	x		x													V	Element			x

The analytical investigation of experimental data form the largest section of the dissertation. It consists of two types of studies.

The first type of studies is a series of categorizations of the experimental data into concrete typologies as well as principles of formwork construction. The series may be very difficult to understand by itself and is only briefly accompanied by a descriptive text. Instead the categorizations of more than forty sets of experimental data should be read with the appendix at hand. This way, the reader can connect the complex taxonomic icons with the readily understandable formwork principles behind them. This will also allow the individual experiments, which are only briefly summarized in the printed appendix, to be placed in a larger context.

The categorization work establishes a focus on three common formwork-tectonic elements, the frame, the form tie, and the textile; the following three groups of analytical studies focus on one of these specific formwork-tectonic elements. Each group of studies has an introduction to the specific formwork element and the analytical cases. Then follows studies of particular experimental work in which the selected formwork element plays a significant role. Finally the potentials of the studies are summarized and discussed further.

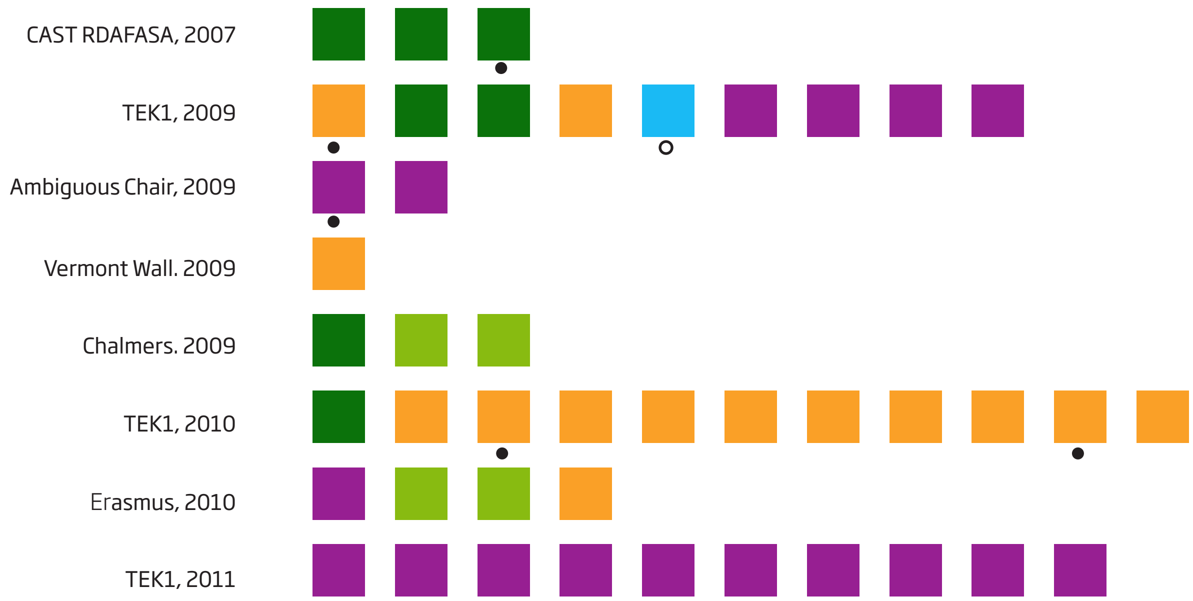
(x) Indicates how the concrete was cast - for example a horizontal bench cast as a column or a sculptural object cast as a wall.

x x x More x's indicate when aconcrete object fits partly into several typologies, such as the legs of a bench.

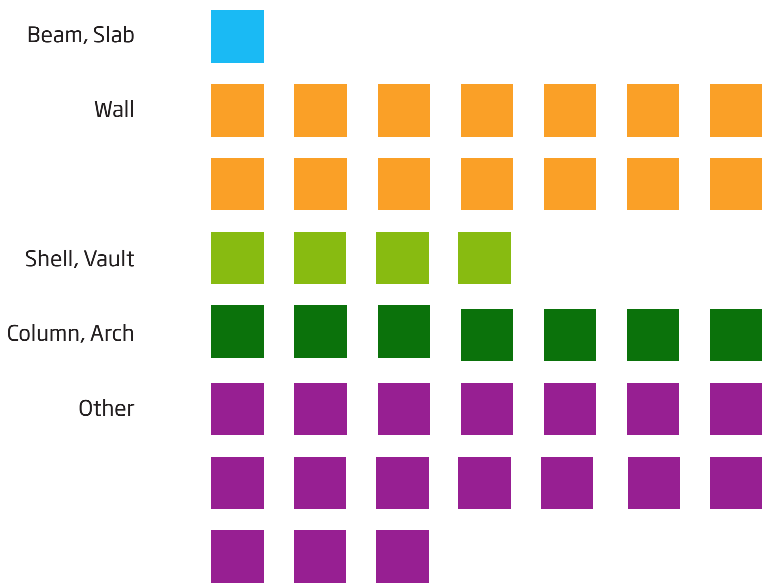
Above, downscaled table of Documentation and Categorization of Experimental Data, which is placed in the Appendix

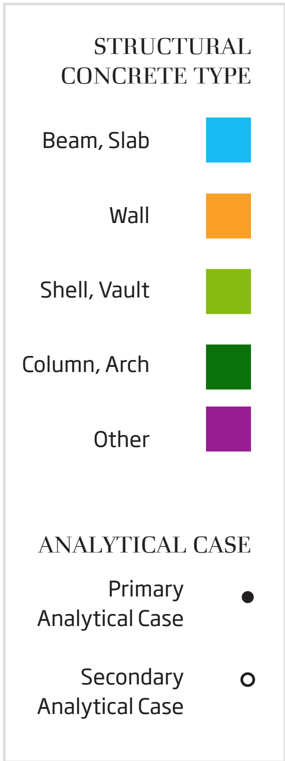
Previous page, an overview of the activities associated with the development of experimental data

CATEGORIZATION II A
Concrete Structural Types pr workshop



CATEGORIZATION II B
Number of Concrete Structural Types





DOCUMENTATION AND COMPARISON

This chapter contains the initial comparative analyses of structures established during the experiments in September, 2007-March, 2010, and supplemented with subsequent data. The structural-physical principles of the experiments are laid out.

The large accompanying table consists of the following main categories:
- structural typology
- concrete concepts and
- structural formwork principles

The former is a way to describe the 'results,' the latter a way to describe the process.

Experimental work[1] was initially categorized on a descriptive instrumental level concerning the kinds of concrete typologies that were represented, and the structural formwork principles. (*Categorization II B*)

The concrete objects were first described via their concrete typology: column, wall, slab, sculptural object. Next, formwork principles were listed with regard to the rigid framing principle, the structural role of the textile, the relationship of the textile to the frame, and the type of restraint.

Due to the wall element assignment for TEK1 in 2009, many walls were represented in the typological table, including suspended fabrics in a frame and different kinds of restraining principles. The frame principles included a high representation of a type called *rigid back*. This term simply covers formwork structures with fabric on one side and a rigid piece of plywood on the other.[2]

Three common tectonic formwork elements were in use in most of the formwork structures: the frame, the textile, and the form tie.[3] A closer look at these dissected categories into different structural principles revealed some new types.
- The listing of the frames was not very productive. The list is basically a list of textile tensioning principles and not much of a literal frame.
- The form tie as a structural element had a wide range of interesting features.
- The textile as a structural element had the most interesting potentials and quite diverse characters. The textile could either be *structurally embraced* in the structure, it could itself act as an *embracing agent*, or it could work in relation with another material used as a formwork element, either a *composite fabric* or a *composite formwork*.

No direct conclusions could be drawn, because there was so much new information to be read out of the table. Many of the structural principles were formulated so vaguely and varied to an extent that made it difficult to actually compare the principles as intended. As implied above, it was clear that the interesting findings in the table were formulated when structural principles clearly overlapped. The *composite formwork* and the *embraced textile*, for example, both contained restraining principles.

The textile was the new formwork element and this 'required' a new objective terminology; perhaps the reason that it was so difficult to categorize the structural role of the form tie was that the experiments indicated completely new types that have additional features compared to previous notions of the form tie as a structural clamp? One might apply a similar hypothesis to the structural roles of the frame – are there new frame typologies that widen the notion of the formwork frame from structural falsework to include levels of rhetorical significance?

Summary of initial categorization

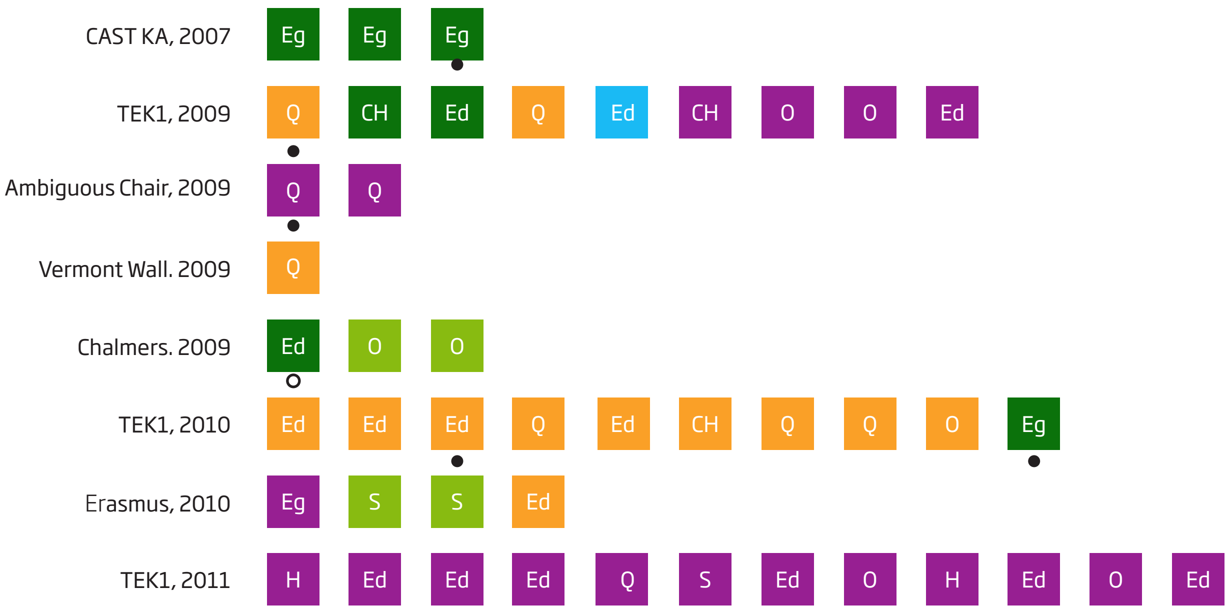
- The concrete objects were described and explained by means of a large typological table.
- Three basic formwork elements appeared throughout the taxonomy: the frame, the textile, and the form tie.
- The typological categorization did not tell the full story of the stereogeneous consequences.
- The technological roles of the formwork elements were only conveyed as instrumental.
- Some formwork elements appeared to 'act' between categories.

1 Columns for Creative Systems, 2007; TEK1, 2009; Ambiguous Chair; Vermont Wall; Concrete Flesh, Chalmers; and Tek1, 2010

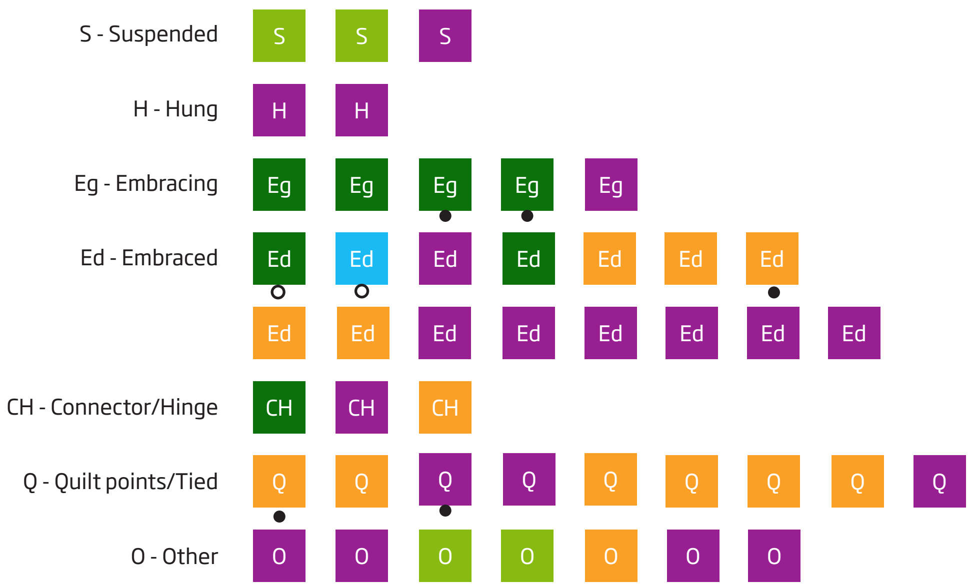
2 Devised by students to express 'soft' and 'rigid' concrete, see for example Butt Wall, 2010 in the appendix. The students' notion of the rigid and soft materials also covered the structural stability of the formwork materials; plywood was considered 'sturdier' than the polypropylene weave, which caused the formwork structures to blow in the often loosely connected rigid corners.

3 The form tie was named 'restraint' in the table.

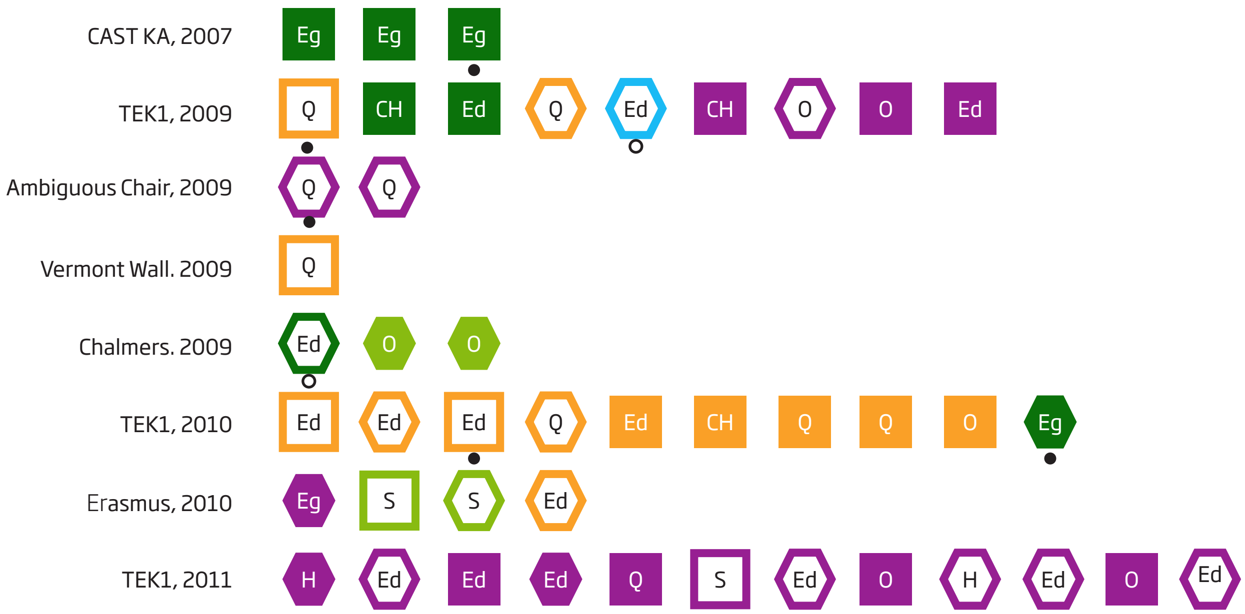
CATEGORIZATION III A
Structural role of textile - Number Pr Workshop



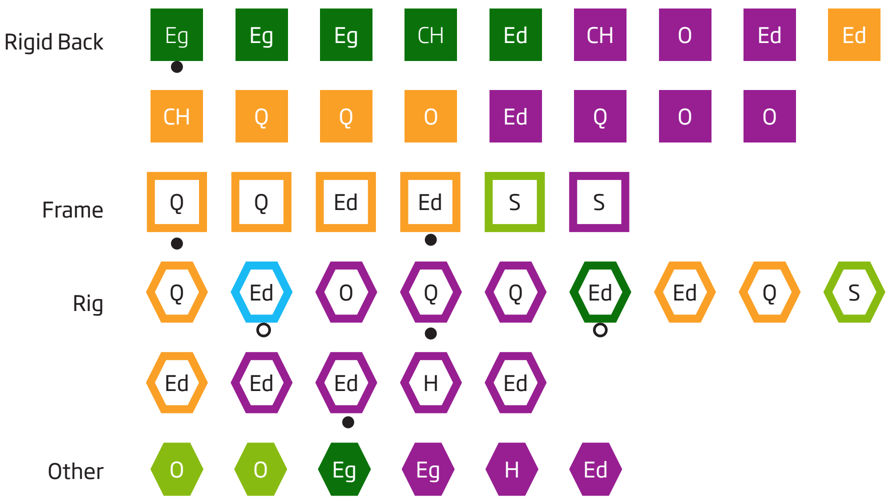
CATEGORIZATION III B
Structural role of textile - Number pr Type

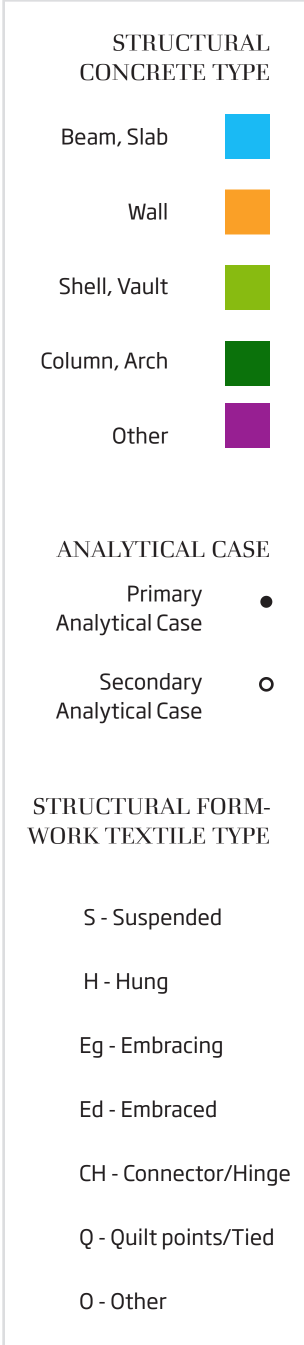


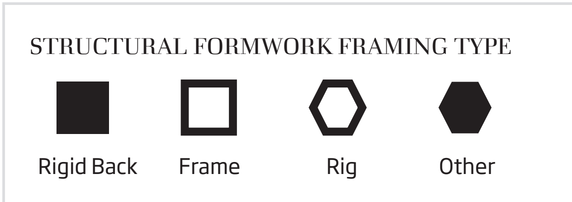
CATEGORIZATION IV A
Structural formwork Type - Pr Workshop



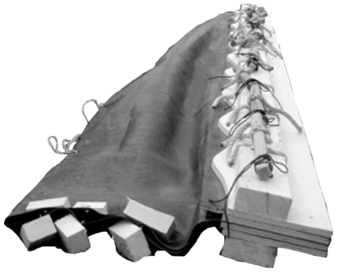
CATEGORIZATION IV B
Structural formwork Type - Number pr Type







Column | Beam | Wall | Shell | Sculptural object

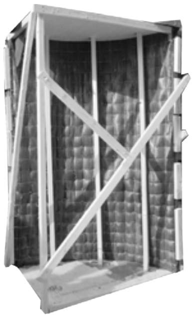

Sinus Column

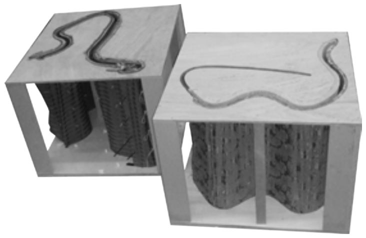

Form-Efficient Beam


Clamp Wall


Fabric-Formed Rigid Mold


Composite Column


Net Wall


Ambiguous Chair

TYPOLOGY	TITLE	PARTICULAR FORMWORK ELEMENT	CONTEXT
COLUMN	Sinus Column	FRAME	CAST, Exhibition 2007
COLUMN	Composite Column	TEXTILE	PhD, TEK1, 2010
BEAM	Form-Efficient Beam	FRAME	PhD, ESALA 2007-10
WALL	Clamp Wall	FORM TIE	TEK1, 2009
WALL	Net Wall	FORM TIE	TEK1, 2010
SHELL	Fabric-Formed Rigid Mold	TEXTILE	CAST 2009
SCULPTURE	Ambiguous Chair	TEXTILE	PhD, Exhibition 2009

PRESENTATION OF ANALYTICAL CASES

'Understanding' construction requires grasping it intellectually after grasping it materially, with all our senses.'[1]

The previous chapter described the initial categorization of structural typologies from the experimental data as an attempt to elaborate on a practice described by Pedreschi in which concrete objects are described according their form, although the objects are explained in terms of process.[2]

The initial categorization in the typological table described instrumental roles of formwork elements of the experimental cases, the concrete typologies, and the constructed formwork principles. The format did not allow for an analysis of rhetorical aspects or any relationships between ideas, processes, and materiality.

Selection of analytical cases

An approach that enables a study of rhetorical aspects of the experimental data also begins with a selection based on formal typology and expression and how and why were they achieved.

The cases selected for analysis have been chosen from experimental data produced at RDAFASA throughout the workshops that have been part of the present thesis work.

During the workshops concrete typologies such as walls, columns, and sculptural objects were constructed and are represented in the studies. Furthermore, experimental work from CAST at the University of Manitoba and the School of Architecture at the University of Edinburgh has been included in the section. These institutions have done research into thin shells and form-optimized beams, these are concrete typologies that were not constructed in the workshops. These examples also represent a focus on repeatability of procedures and the serial production of concrete elements.. The latter is of crucial importance for construction.

The form-typologies included in the analytical cases cover all the main structural typologies made in concrete: column, beam, wall, shell, and a freestanding sculptural object (chair). In order to explain these forms, the analysis examines the process of their becoming. In this regard, the analytical cases have been grouped according to their dominant formwork-tectonic element: frame, form tie, and textile.

Explanation and interpretation

The following chapters form a series of analytical studies of experimental data from the exploration of fabric formwork.

Eduards Sekler's model of *Structure, Construction and Tectonics* is adapted to posit a *Steregeneity*. that can be defined as the expressed material manifestation of the combination of initial structural formwork principles and the following construction process.

Frame, form tie, textile

A specific tectonic formwork element is used as the focusing tool in order to examine the procedures and stereogeneity.

It is the aim of the following range of analytical studies to identify and discuss dual-sided technological roles of the principal tectonic formwork elements: *frame*, *form tie*, and *textile*. The roles are discussed in regard to their different conditions throughout the experimental studies.

The hypothesis here is that *this emphasis on particular formwork elements and their signifying roles can inform the articulation of specific potentials for fabric formwork and add further layers and nuances to the concept of concrete as an architectural material and process.*

The analytical cases in the seven studies vary in length and content due to different purposes, contexts, and concreting methods. Despite these differences, also differences in complexity, the individual works share several issues with regard to as-yet unnamed instrumental and rhetorical roles of formwork elements in fabric formwork.

Interpretation of experimental architectural data

This chapter is an attempt to draw a more complex picture of the experimental data based on its construing and construction. In doing so, a wide range of experimental data is analyzed in order to shed light on intentions and formwork principles for the fabric-formed concrete pieces and on the that was applied to achieve the intentions.

Architectural drawings by the makers of the experimental data may be read as Marco Frascari reads the drawings by Carlo Scarpa, as *"construing of perceptual judgments interfaced with the real process of physical construction of an architectural object."*[3]

The students' architectural aims deal with the sculptural expression of concrete. Furthermore the students naturally have much less experience with construction than Scarpa did. Hence, the *real* process of physical construction is in fact much closer to an *imagined* process of physical construction.

1 Deplazes, *Constructing Architecture*, 19.
2 Chandler and Pedreschi, *Fabric Formwork, 24*.
3 Frascari, "The Tell-the-Tale Detail," 507.

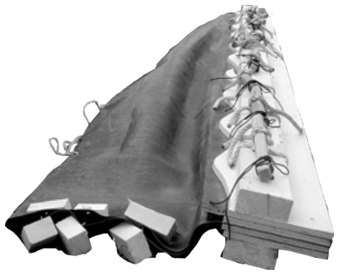
ANALYTICAL STUDIES OF THE FRAME

INTRODUCTION TO THE FRAME

STUDY OF THE SINUS COLUMN

STUDY OF THE FORM-EFFICIENT BEAM

POTENTIALS OF THE FRAME



Sinus Column by CAST

Form-Efficient Beam by Daniel Sang-Hoon Lee, ESALA

TYPOLOGY	TITLE	PARTICULAR FORMWORK ELEMENT	CONTEXT
COLUMN	Sinus Column	FRAME	CAST, Exhibition 2007
COLUMN	Composite Column	TEXTILE	PhD, TEK1, 2010
BEAM	Form-Efficient Beam	FRAME	PhD, ESALA 2007-10
WALL	Clamp Wall	FORM TIE	TEK1, 2009
WALL	Net Wall	FORM TIE	TEK1, 2010
SHELL	Fabric-Formed Rigid Mold	TEXTILE	CAST 2009
SCULPTURE	Ambiguous Chair	TEXTILE	PhD, Exhibition 2009

INTRODUCTION TO THE FRAME

The use of the formwork frame as a dominant formwork tectonic feature is studied in two experimental cases: the *Sinus Column* and the *Form-Efficient Beam*.

Technically, the frame is part of the boundary condition for the tensioned formwork membrane. It functions as a textile suspension devise. As stated in the fabric formwork introduction, this entails the conceptually linked opposition bound to 'releasing form'. The relation between tension and release is fundamental to fabric-forming.[1]

The technical principle and conceptual notion of the frame thus take on significant relevance in fabric formwork for in situ construction and is due to the direct stereogeneous consequence of the frame and restraining elements for the formwork fabric.[2] This formal expression of the technical role of the frame is unusual in rigid formwork systems, in which the frame remains hidden on the exterior of the formwork shuttering as a bracing element.

The direct stereogeneous consequence of the frame is a feature of the two examples discussed here.

The intention behind each of the examples is divided between the construction of a column to display the sculptural and practical potentials of the simple means of fabric formwork and, on the other hand, the development of a method with the aim of producing form-optimized concrete beams in formwork as efficiently as possible.

Typologically, the experiments represent two basic construction elements: the concrete column and the beam, and two modes of construction: the *Sinus Column* is poured vertically in situ, and the *Form-Optimized Fabric-Formed Beam* is a horizontally poured element.

In this regard the structural role of the frame also varies; The frame for the column acts both as a vertical brace for the formwork structure and as the mechanical closure device for the textile formwork sheet. The frame for the beam is shaped to produce the most optimized form.

Question

What is the consequence of new roles for the formwork frame when conventional rigid formwork sheets are replaced with dynamic fabric and the frame becomes visible. When the conventional flat concrete surface is replaced with bulges, and the frame may suddenly appear as an impacto, an emphasis of the tectonic relation with the other rigid formwork elements in the construction of concrete?

1 States Professor Remo Pedreschi in his lecture at the ICFF 2008 at the University of Manitoba. It is fundamental for the formwork method as well as the teaching during workshops at ESALA.

2 Abdelgader, West, and Gorski, "SoA Fabric Formwork," the authors refer to it as the boundary condition. This is also introduced in the Fabric Formwork chapter.

STUDY OF THE SINUS COLUMN

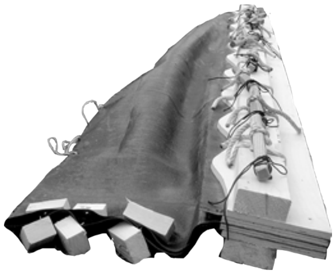
Authors: Center of Architectural Structures and Technology(CAST) at the University of Manitoba)
Mark West and Aynslee Hurdal.
Assistant: Anne-Mette Manelius

Where: CAST and RDAFASA
Year: 2007
Context: Exhibition

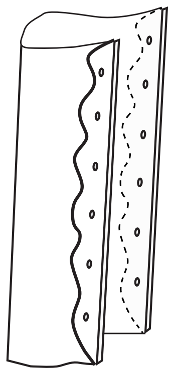
STUDY OF THE SINUS COLUMN

Structural typology of concrete:	Column
Structural typology of formwork:	'Vertical lath'
Structural role of fabric in formwork:	Structural Container
Reinforcement:	8 mm rebar tied to foundation rebar
Concrete type:	SCC (old = very dry)
Concrete procedure:	Pour (from truck)
Other	'Pinches' create an ornament
Short description of formwork principle	A folded sheet of textile is closed with a rigid clamping device that also works as the vertical rig/brace. Geometric 2D cut of the clamp affects the formal geometry of the column.

Eg



Fornwork for Sinus Column



The jacket formwork principle with vertical bracing.

The formwork for a fabric-formed concrete column is the simplest structural principle to construct using fabric formwork. The *Sinus Column* has a special undulated profile, the result of a simple articulation of a necessary joining of formwork materials.

The formwork principle consists of a sheet of textile and one vertical brace, which is defined as a frame in this study and has multiple technological roles. What are the rhetorical and instrumental roles of the frame for the *Sinus Column*; what are the stereogeneous consequences of the frame; and which textile qualities does the frame enhance in the transfer to concrete construction?

The Sinus Column and its context

The analytical case was one of the first three full-scale fabric-formed concrete structures to be constructed in Denmark.

The cultural context of the experiment was a conference and exhibition.[1] The column was one out of three created for the occasion; the fabric, tools and special connectors, so-called Thai –Ties, were brought in a duffle bag from Canada to illustrate the simple and lightweight aspects of the construction technique.

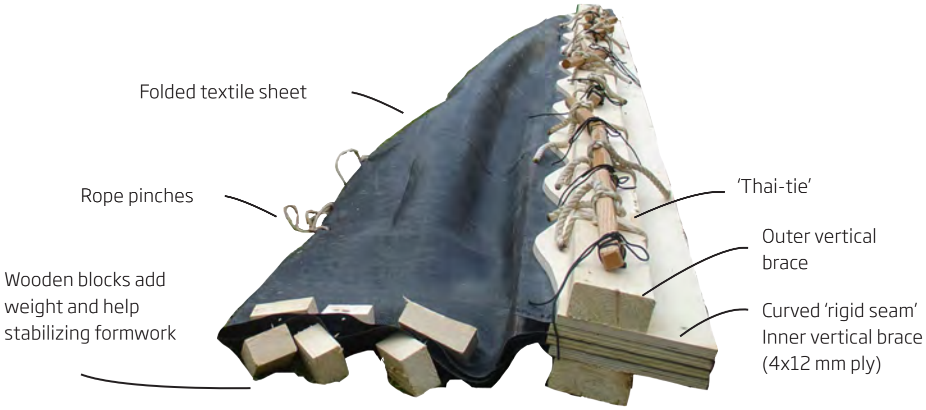
The scientific context was to communicate and display the technique, with simple means and little time to create articulated concrete structures.

1 *'Creative Systems,'* RDAFASA, September 2007, organized and hosted CINARK directed by Anne Beim.

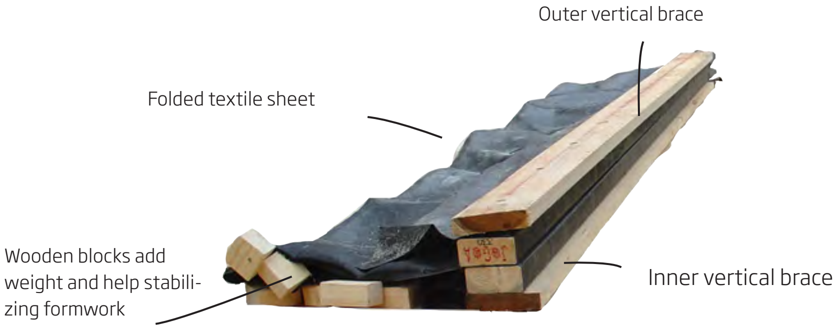
Students with fabric-formed columns cast for the Creative Systems conference and exhibition, 2007. From left: the *Voodoo Column*, the *Fast-Tube* Column, and the *Sinus Column* (Appendix, workshop 1)

Three columns are poured, Sinus Column is on the left

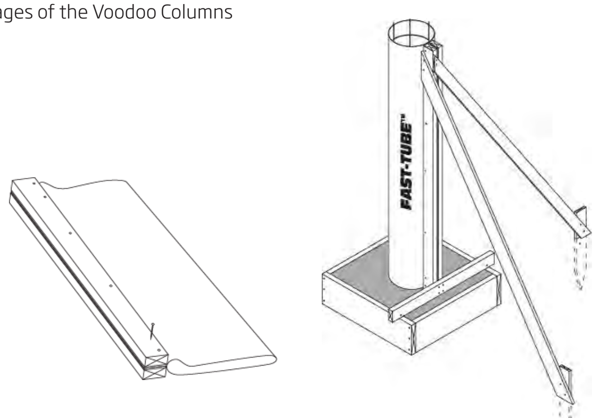
Compacting the concrete from the outside. Left, stripping the formwork



'Rigid seam'/vertical bracing for the Sinus Column.
Photographed after 'Thai-ties' are placed through the vertical brace boards.



The Voodoo Column. Simple 'rigid seam/vertical bracing for fabric formed column.
Photographed before clamps or ties are placed through the four vertical brace boards. See appendix / 1 for more images of the Voodoo Columns



Fast-tube™, fabric formed column formwork from high strength polyethylene. The formwork tube is already closed by welding and arrives with a fixed diameter and an 'allignment tab'. Braces are simply screwed together sandwiching the tab. See also appendix / 1.

Construction process for the Sinus Column

Each end of a folded sheet of fabric is folded wrapped around and stapled to a plywood board; the boards are then sandwiched between identically cut plywood boards with curved edges extending into the formwork area; the whole construction is held together by a set of laths. All six layers of wood and the fabric have holes drilled through them. The frame is closed using Thai-Ties,[2] a simple connection system that consists of a stick, a rope, and a ribbon or piece of string[see illustration].

Rope is used to create pinches on the textile surface; another illustration of the textile principles and the simple means that are capable of larger stereogeneous consequences.

The formwork was assembled on the ground and eventually erected; only then came the realization that the foundation was uneven.[3] Due to the time pressure, the idea of extending the textile with an overlapping piece of textile or simply adding duct tape to the textile did not present itself. Instead, wooden 'rings' were placed under the textile to fill the gap between formwork and foundation, which could be crucial when pouring very fluid, self-compacting concrete.

When the concrete truck arrived the SCC concrete was 'old',[4] and the concrete was very dry and in fact far from self-compacting. This affected the pour.

Stereogeneity of the Sinus Column

The concrete column has an articulated profile; the sinus curve and the effect caused by the *pinching*, cause the concrete surface to bulgeundulate in between the pinched areas.

The concrete surface appears uneven with numerous blowholes and honeycombs; the surface has an embedded structure created by the coarse pp-weave.

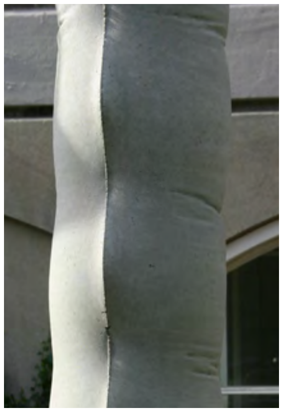
The concrete structure with the strong imprint of the textile tells the story of its geneity; it is quite clear that something has pinched the textile and caused the undulated surface to emerge. This surface seems to correspond clearly with the behavior of textiles under hydrostatic pressure. The vertical sinus curve may be less obvious; one has to think of textile as a container in order to realize that the articulated profile may be a significant part of the formwork.

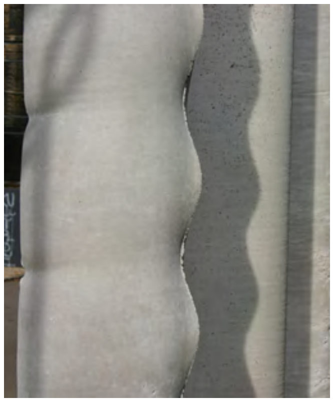
The formwork principle has direct formal consequences, but how clearly does the sterogenity of the column express its becoming? The piece forces one to consider the construction process and mentally reconstruct the processes that would have shaped the column.

Upon further study, it becomes clear that the column is not completely straight; it 'sags'. This sagging tells the tale of liquid concrete poured into responsive formwork that is not completely vertical. The 'rings' shifted during the pour and caused the deformation of the intended straight column.

The small shift in a formwork element caused severe deformation in the geometry of the concrete structure. This detail is important to keep in mind later, when we discuss the implementation of fabric formwork in construction.

The Sinus Column sags. A small shift in a formwork element caused deformation in the geometry of the formwork and caused formwork to sag. Below, the stereogeneous consequence of the sinus-shaped closure.





Rigid seam in the three columns at RDAFASA – the seam is highly articulated for the Sinus Column (left)

The roles of the frame in the Sinus Column

The construction of the *Sinus Column* was part of the first-ever exhibition of fabric formwork in Denmark.[5] The frame is the initial subject of this analysis, but the role of the frame must be considered in combination with the roles of the other formwork elements in order to grasp the whole; the role of all formwork elements of the *Sinus Column* will be briefly unfolded here.

The simplicity of the formwork structure displays all the elements at hand in fabric formwork and the manner in which the textile, responsive formwork is affected by the other elements. Rigid formwork members can create sharp edges and outlines of the concrete structure; this effect is contrasted by the possibilities of exploiting the properties of textile with the simple means of a tailor, such as the precision placement of pinches, creases and folds.

The roles of the frame

The instrumental role of the frame is to serve as a closing device for the textile mold and as part of the vertical bracing of the formwork structure

The symbolic role of the frame is to serve as form-maker defined by the tools of the form-giver; the simple curvature cut into the two plywood sheets has stereogeneous consequences on the concrete structure with regards to both materiality and process.

First, the concrete form is the direct formal consequence of the geometry of the frame through the geometric effect upon the textile tube. The materiality of the column is articulated accordingly.

Second, through the signified concrete form its geneity is emphasized, and the 'seam' is highlighted and displays the role of the rigid frame as a signifier in the formwork structure.

The roles of rope

Small pieces of rope play an important role in the frame for the *Sinus Column* as thin rope is used as an alternative to industrial clamps[6] to tie the bracing frame together and thus illustrates the set of fundamental rules at CAST of Appropriate Construction,[7] inspired by the Uruguayan builder Eladio Dieste.[8] The design rules at CAST guide research to use as simple means as possible out of ethical thinking. Dieste's ,principles of appropriateness are based on fundamental ethical as well as economical conditions.

The *instrumental role* of these Thai-Ties is to serve as a clamp to literally tie the vertical frame firmly together the ties are lightweight and convenient for travelling, and thus, a *symbolic* role of the Thai-Tie is the expression of a general simplicity of construction.

Additional pieces of thin rope are used to *pinch* the fabric sheet, in this case for purely ornamental reasons; this gives the rope a symbolic role and emphasizes the responsive aspect of textiles used as concrete formwork; one little pinch and a piece of rope can generate a highly elaborate stereogeneous effect. Similar but not identical to the symbolic role of the *frame*, the rope alters the behavior and geometry of the textile through a small manipulation of its surface. The rope is the signifier here, but perhaps more importantly, it also reveals the textile

2 Mark West, "The Thai-Tie, A Powerful, Simple, Inexpensive Connector", (CAST, University of Manitoba, January 30, 2010), www.umanitoba.ca/cast_building, (Accessed 22-11-2011). Mark West has seen the ties used on construction sites in Thailand but suggests that they are used elsewhere.

3 Due to difficulties in the communication between CAST and RDAFASA and the inexperience by the author and lack of adequate tools at RDAFASA, the construction process took longer than expected, and the preliminary concrete foundation work was not level.

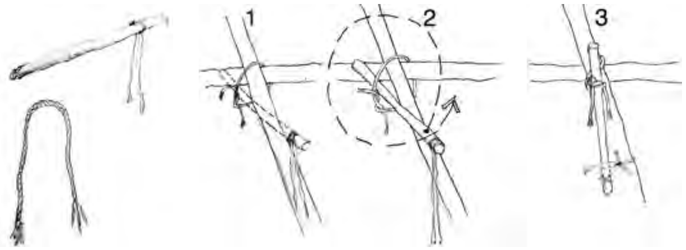
4 Students in another concrete workshop at RDAFASA used concrete from the truck first. It was a mistake to combine the deliveries or to let the inexperienced group go first, as it took a long time to pour their small and delicate pieces.

5 Karl Christiansen and Anders Gammelgaard, "Industrialiseret Individualitet," *Arkitekten*, no. 1, Teknisk Tema: Systemleverancer (2006): 55–59. Researchers at the Aarhus School of Architecture have explored formwork systems with flexible membrane to create undulating surfaces in prefabricated concrete elements.

6 The frames for neighboring columns were tied using conventional, heavy industrial metal clamps supplied by the contractor E. Pihl & Søn.

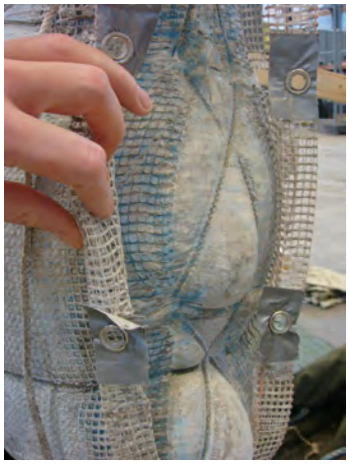
7 CAST, "Appropriate Construction", 2010, http://www.umanitoba.ca/cast_building/research/appropriate_construction.html. (Accessed 22-11-2011).The web site of CAST states rules of appropriate construciton at the research center: 1: Use only common and inexpensive materials; 2: Use only common and basic tools and techniques – the more "primitive" the better; 3: Rely on fundamental natural law for technical guidance.

8 Remo Pedreschi, *The Engineer's contribution to contemporary architecture: Eladio Dieste* (London, England: Thomas Telford Ltd, 2000), 17. Dieste aimed for an appropriate architectural language and for the using use of inexpensive, indigenous materials



Top: The Thai-Tie consists of a stick, a rope, and a small piece of ribbon or string, (West, 2010)

Rope pinches on the formwork the day after the pour. (Left image). Detail of the concrete surface where the rope pinch has been. (Right image)



Seam in hung formwork. The articulated seam is made from a tied jacket (glas fiber net) around an inner spandex tube. Chalmers Column, 2009. (Appendix, workshop 5.1)

behavior in between the undulated concrete surface and the obvious marks from the pinches that caused the undulation.

In this sense it becomes clear that the formwork of a large concrete column can literally be constructed by very simple means: rope, a wooden stick, textile and the straight boards for the vertical frame/brace. For this simple application, the textile will not be perforated much, and the formwork can be reused for other pours.

DISCUSSION OF THE THE SINUS COLUMN

The rigid seam

The instrumental role of the frame is to serve as a large clamp device. In our textile terminology, the formwork frame for the *Sinus Column* might be called a *rigid seam*.

The articulated joint of the formwork structure is an example of the Semperian notion of the signified seam.

"The principle of making a virtue out of necessity.
It teaches us that anything that is and must be a patchwork, because the material and means at our disposal are insufficient, should not be made to appear otherwise. If something is originally separate we should characterize it not as one and undivided but, by deliberately stressing how the parts are connected and interlaced toward a common end, all the more eloquently as coordinated and unified." [9]

Semper refers to the connections of parts and architectural elements in this passage, but it is also relevant to look at the principle applied in closing the fabric formwork sheet for the *Sinus Column*. Thus, the analytical case illustrates the Semperian terminology where the *seam* was introduced as an important axiom for artistic practice and covers more than mere textile application: It is the universal notion of joining pieces of a homogeneous nature into a whole.

As with any *Semperian* seam, the *rigid seam* offers multiple ornamental possibilities suitable for making a virtue out of necessity; in the *Sinus Column* the ornamental potential is formed as a curve that is simple to construct by cutting a plywood sheet, and which has a distinct stereogeneous consequence.
The column still appears monolithic, stereogeneous; yet the traces of the articulated juxtaposition of formwork materials also signify the concrete structure.
Folding and closing the textile sheet into a formwork tube will necessarily leave a visible joint, which is articulated in the case of the *Sinus Column.*

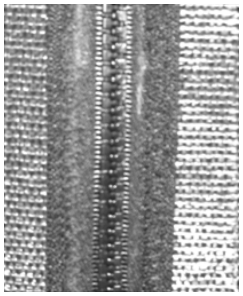
9 Semper, *Style*, 154.

Seam made from metal wire tied in points, Vermont Wall 2009 (Appendix, workshop 4)

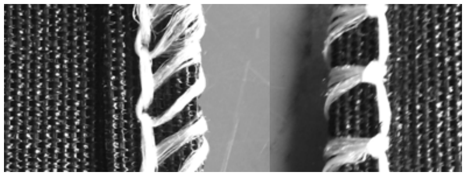
Concrete objects were cast to observe the traces from specific seams

Seam | Concrete detail

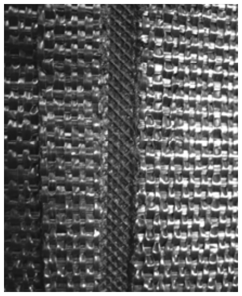
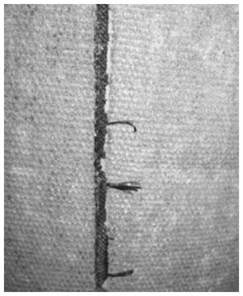

Laced seam. An extra membrane layer is placed on the inside



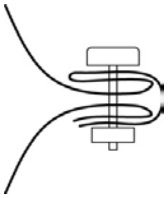

Zipper seam




Overlock seam and the concrete detail

Heat welded seam, Parts of the weld were left embedded in the concrete.



Bolted seam and the concrete detail. The drawing may not represent the actual detail. See another detail drawing on page 182


Seam from overlapping textile and rope.

All illustrations on this page are reproduced from the diploma dissertation by Sørensen and Wonsild

Articulated seams in fabric formwork

The images on the left are illustrations of experimental work in a diploma project in Architectural Engineering.[10] Based on the idea of tailoring fabric formwork the project studied and tested a variety of seams, including the strong industrial double-loop stitch, a type of strong lockstitch.[11] The conventional seams (welding and stithes) were strong but could not be handled on site. Also these methods caused textile to be stuck in the concrete.[12] Students found the zipper simple to close, and it left a clear imprint; the formwork could not be unzipped because of concrete in the zipper.[13]

Examples of techniques for formwork seams to close and open on site for other include ties, laces and bolts.

These techniques have only been used as seams in structurally hung or suspended formwork. The formwork for the *Sinus Column* was vertically braced; the frame seam in the formwork thus served the dual purpose of closing the form *and* structurally bracing the formwork structure.

Flaws with formal consequences

There is an important general note to be made with regard to the practicalities of construction. Miscommunication during the construction of the formwork for the *Sinus Column* caused the columns to sag. Explorations of fabric formwork focus on the direct stereogeneous consequence of the formwork principles for their formal and tactile potentials. As the example shows, the direct response of the fabric to the hydrostatic pressure of the formwork means that miscommunication or poor workmanship also have direct consequences.

In conclusion

The *Rigid Seam* can be defined as a linear and rigid closing device or as the articulated framing device for a fabric form. It combines the Semperian role of the seam to make a virtue out of necessity with the structural roles of frames and braces in formwork. This coupling of rhetorical and technical aspects of the closing and bracing element in this analytical study can thus be seen as an important qualification of the frame in the tectonic vocabulary of fabric formwork.

10 Sørensen, Jannie Bakkær, and Ida Højgaard Wonsild. "Vævet Geotekstil Som Tekstilforskalling (Woven Geo-textile as Fabric Formwork)". Diploma project, Architectural Engineering, Technical University of Denmark, 2008. Supervisors Kurt Kielsgaard Hansen, Lotte Bjerregaard Jensen, Anne-Mette Manelius

11 The lockstitches belong are one of to the 300 stitch classes in the stitch classification system found defined in ISO 4915. ""Lockstiching is the strongest form of stictch but it does need two sided access." E-mail of October 21, 2011, from Julian Ellis, CEO Ellis Developments Ltd, Ellis Developments is a research and development textile company specializing specializing in technical textiles. Their expertice is mainly in two areas, composites and medical textiles. www.ellisdev.co.uk

12 This practical experience is emphasized by an industrial expert. "To join a slippery fabric from polypropylene one would need to turn the edge of both edges of fabric so that the fabric did not unravel when loaded." In eE-mail to AMM of October 21, 2011, from Julian Ellis, CEO Ellis Developments Ltd, www.ellisdev.co.uk

13 Brennan, "Pile Jackets", n.d., http://www.jfbrennan.com/ConcreteRepairs_PileJackets.html. Zippers are in fact used as closing devises devices for commercial pile jackets.

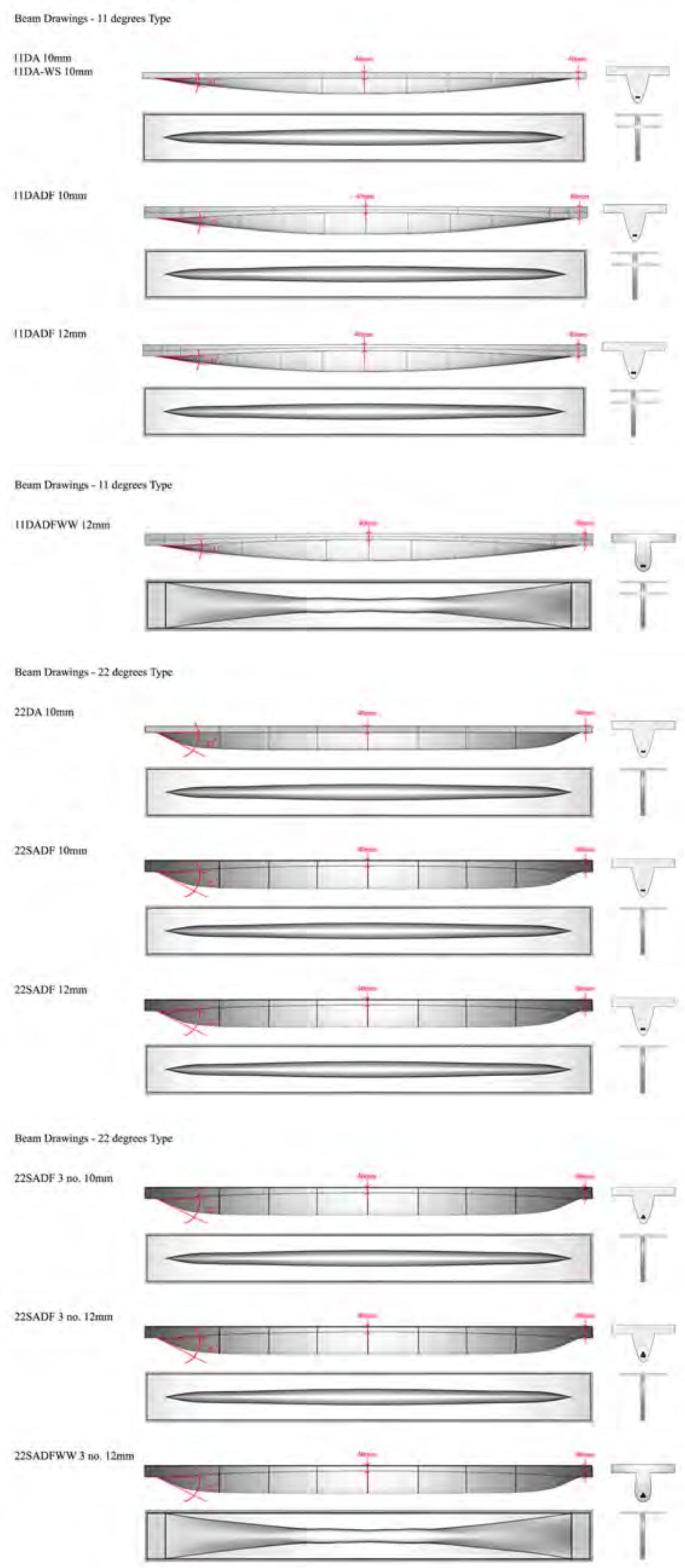
STUDY OF THE
FORM-EFFICIENT BEAM

Author: Daniel Sang-Hoon Lee

Where: Edinburgh School of Architecture and Landscape Archiecture at the University of Edinburgh

Year: 2005-2011

Context: PhD work,


Beam Drawings - 11 degrees Type
11DA 10mm
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11DADF 10mm
11DADF 12mm
Beam Drawings - 11 degrees Type
11DADFWW 12mm
Beam Drawings - 22 degrees Type
22DA 10mm
22SADF 10mm
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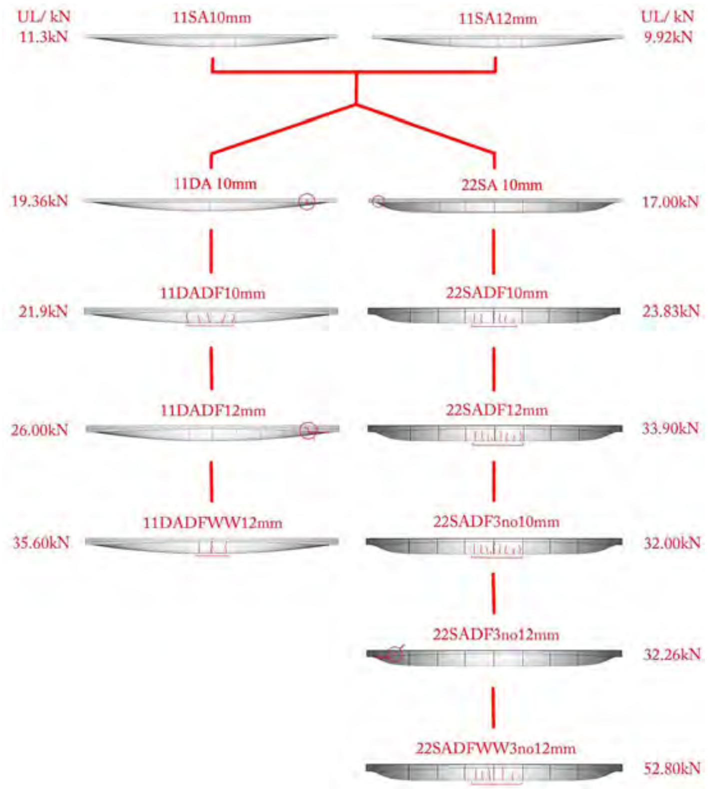
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23.83kN
26.00kN
11DADF12mm
22SADF12mm
33.90kN
35.60kN
11DADFWW12mm
22SADF3no10mm
32.00kN
22SADF3no12mm
32.26kN
22SADFWW3no12mm
52.80kN

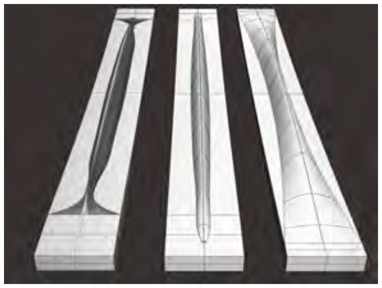
STUDY OF THE FORM-EFFICIENT BEAM

Structural typology of concrete	Beam
Structural typology of formwork	Rig
Role of fabric in formwork	Suspended
Reinforcement:	Curved acording to bending moment
Concrete type:	10mm round aggregates
Concrete procedure:	Pour
Short description of formwork principle	Formwork principle developed to construct and test a T-beam with a double-curved surface cast in polypropylene fabric suspended in a specially made frame.

Form-Efficient Beam

The experimental data for the analytical study of the *Form-Efficient Beam* is a PhD dissertation by the South Korean engineer Daniel Sang-Hoon Lee undertaken at the School of Architecture at the University of Edinburgh[1] entitled: "*Study of Construction Methodology and Structural Behaviour of Fabric-formed Form-efficient Reinforced Concrete Beam*".[2] In the following, this work will be referred to as the *Form-Efficient Beam.* Sang-Hoon Lee's dissertation describes the development of formwork principles and construction techniques for a form-optimized concrete beam designed and tested in regard to the optimized use of concrete and formwork materials. Possible applications of the formwork method in contemporary construction are also suggested in the report.[3]

Unless otherwise indicated, all illustrations in this study are courtesy of Sang-Hoon Lee. In some images, the motive has been 'cut out' by AMM.



Three tyoes of beam developed by Sang-Hoon Lee

As the title of Sang-Hoon Lee's dissertation indicates, efficient forms are related to the utilization of material; in a structurally efficient form, the induced stress closely matches the capacity of the material. Form-efficient structures thus have an efficient distribution and use of materials.

Three principles can describe ways of form-optimizing concrete beams: The beams can be hollow, inspired by bone structures; they can be constructed with a variation of sections to accommodate differences in the induced stress on structures; or they can be formed with 'extruded' profiles as variations on Is, Ts and Ls.

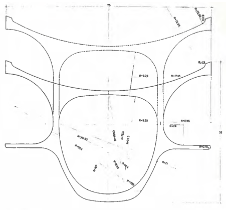
This case is different from the other analytical cases in the present dissertation because the aim of the work uses the new formwork technology, fabric formwork, to increase the level of simple buildability[4] of efficient geometries in a well-known structural typology, the beam.

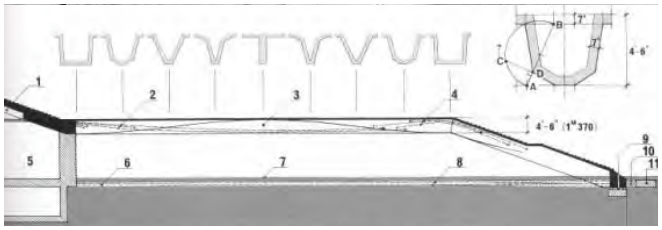
Opposite page: ten types of fabric-formed beams constructed and tested by Sang-Hoon Lee. The diagram to the right indicates the increase in tensile strength of the beam over the course of the thesis work.

1 The school will also be referred to here as ESALA, i.e. Edinburgh School of Architecture and Landscape Architecture.

2 Daniel Sang-Hoon Lee, "Study of Construction Methodology and Structural Behaviour of Fabric-formed Form-efficient Reinforced Concrete Beam" (PhD-Dissertation, Department of Architecture, University of Edinburgh, 2011).

3 Ibid., 5–6.





Top: Pretensioned TT-beams (Spæncom.dk)
Left: Sections of prestressed 'Bone Beam' for roof, Different heights allow water to drain off the top without need to incline the piece. the Miguel Fisac (Soler 1996, p138)

Right: Single span beams under Monumental Steps of the Sydney Opera House, Australia 1957-73. Some up to 49 meters long (State Library of New South Wales, Australia).
Bottom: Cross and longitudal sections of the beam

The experimental study of Sang-Hoon Lee's form-optimized beam deals with a T-beam with a variable section of web (the vertical 'fin' of the beam) and flange (the top/horizontal parts of the T-shape).
The formwork principle has three types, which represent three stages in the development of the beam design. A shared feature of all three types is a rigid plywood sheet to restrain the fabric for the flanges and to form the contour of the web. The web is created when fabric under the weight of poured concrete deflects through the opening of the frame.

A total of eleven different types of beams were designed, cast and tested in the work for Sang-Hoon Lee's dissertation, and three different types of fabric formwork were developed and constructed.

Types 1 and 2 consist of variations on oval-shaped holes in the rigid frame-bed and utilize a curved clamp as a *rigid seam*[5] for controlling the curvature of the web. Type 3 is

The focus of this analytical study is the dual-sided technological role of the frame as a specific formwork element in the design and development stages for the beam as well as the discussion of future applications of such a frame or the formwork method developed by Sang-Hoon Lee.

Previous research at the University of Edinburgh

The PhD was developed as part of the '*Fabric formwork Research Programme*',[6] a recent dual-discipline teaching and research practice between architecture and engineering initiated in 2004 by Remo Pedreschi, engineer and professor of Architectural Technology at the University of Edinburgh, and Alan Chandler, architect and senior lecturer at the University of East London,[7] in collaboration with Mark West of CAST.

Since 2004, Pedreschi has organized and taught a reoccurring five-week studio-unit for architecture and engineering students to explore techniques of fabric formwork. Sang-Hoon Lee initiated his PhD work on the background of his participation in one of those workshops.

In this regard, it is relevant to briefly describe the studio unit in which students have been exposed to the technique of fabric formwork from a variety of perspectives that Pedreschi defines as *form*: appropriate architectural elements; *process*: understanding appropriate techniques, and *surface*: the qualities of the form produced and its representation in terms of reflectivity and texture.[8]

The term appropriate is adopted from the practice and writing of the Uruguayan engineer Eladio Dieste (1917-2000), who used it to describe his rational and ethical approach to building materials, the structural potentials of surfaces and their expressiveness, and construction.[9]

From this starting point, student work at the course follows criteria such as the rational use of fabric, minimal use of formwork materials, consistency and control of the process, and focus on the connection between elements.[10]

4 And not only the virtual simulation.

5 As defined in the analytical study of the *Sinus Column*.

6 Alan Chandler and Remo Pedreschi, eds., *Fabric Formwork* (RIBA Publishing, 2007), 6. *'Fabric formwork' is a research programme that seeks to establish techniques that adress complex issues of technical production, risk management and advanced passive energy control, but also accept the legimate responsebility to be comprehensible and relevant to everyday construction and everyday use*' writes Alan Chandler

7 "University of East London - UEL", n.d., http://www.uel.ac.uk/. (Accessed 22-11-2011)

8 Chandler and Pedreschi, *Fabric Formwork*, 23.

9 Ibid., 22. Stanford Anderson, ed., *Eladio Dieste: Innovation in Structural Art* (Princeton Architectural Press, 2004), 187. In his essay, Eladio Dieste states "*The resistant virtues of the structures that we are searching for depend on their form. It is because of their form that they are stable, not because of an awkward accumulation of*

Concrete structural typologies examined at the studio units include beams, columns, shells, walls, and sculptural objects and work revolve around an initial approach to explorations of structures and construction processes. During the 5-week courses typologies change as the structural aims, formwork methods, and construction details become more specific.

Frames and rigs at the University of Edinburgh Workshop Practice

In the study of construction techniques for repeatable casts at the workshops, rigs and frames appear to have been the object of particular attention. Some rigs are adjustable during the pour, which means that the fabric form is constantly tensioned, and entire fabric forms are twisted to create interlacing structures with unprecedented forms and surfaces.[11]

The students' practice can be compared with Eladio Dieste's approach to construction. Dieste developed alternative modes of construction and utilized specially made bricks for the construction of undulating reinforced brick structures that were deeply rational but did not comply with contemporary modes of framed construction.

Pours in these rigs are not full building scale, and the relatively low hydrostatic pressure in low pour-heights make it possible to use fabrics of a variety of qualities ranging from 'domestic' cotton to cotton mixes and sturdier technical polyolefin weaves.

Specific formwork principle used for the experiment

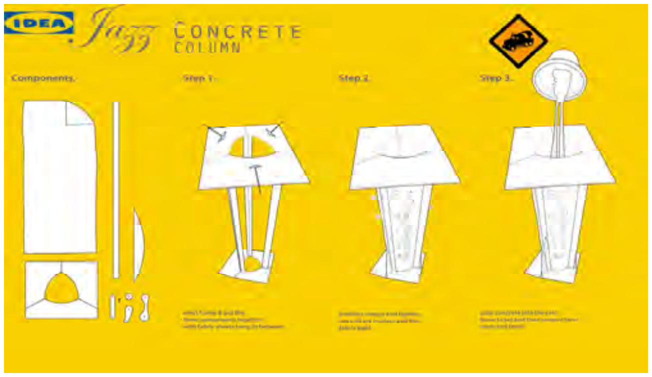
Sang-Hoon Lee refers to the combination of frame and rig as *soffit*[12] formwork and describes an earlier prototype T-beam to
"consist of flange and web, and the formwork was developed with the particular aim of achieving repeatable dimensional accuracy. The fabric formwork was mainly used to form the complex geometry of the web, and the plywood soffit formwork is used to form the flange."[13]

Sang-Hoon Lee's use of the word soffit refers to the underside of the concrete deck and the T-beam; the focus on special types of formwork elements in the present dissertation calls for an attempt at more general descriptions of the frame in the analytical case, so soffit will not be used for the particular frame.

The basic principle is developed and tested in the course of the thesis work, and the principle and construction of three formwork types for the *Form-Efficient B*eam will briefly be summarized in the following.[14]

Rigs for twisted columns. Images shown at ICFF2008 by Remo Pedreschi.

Rig from student work at ESALA, 2007-08



Do It Yourself construction á la IKEA, Illustration of concept from student report, ESALA

Structural formwork principle and construction of three versions of the Form-Efficient Beam

The formwork principle consists of the relationship between the formwork frame and the textile required to obtain the desired geometry of the beam and to achieve a rational process for a repeated production of identical concrete beams; throughout the experimental process, Sang-Hoon Lee alters the frame and the placement of the textile, adjusting the formwork in response to test results from previous tests and digital simulations.

The dissertation presents the development of one coherent framing principle and two ways of positioning the textile in the mold. The definition of the web was suggested either with a clamp or by placing the textile in a particular way. In total, three types of formwork were developed during the development of the beam design through iterative processes of experiment, analysis, evaluation, and modification.[15]

The frame is prepared, and the textile is mounted.

Principle and construction of type 1

The first approach consists of timber soffit formwork for the flange and fabric formwork for the web. The web profile is defined with plywood pieces cut into the curved shape. [16]

Principle and construction of type 2

The modifications to the first formwork type are the 'molding' of the frame as described by Sang-Hoon Lee:

At this point the new design of beam has the flange adopting the parabolic curve to increase the thickness at the supports and hence enhance its capacity against the shear. Thus the additional plywood sheets are put on top of the existing soffit members and curved to the required profile. The plywood sheets are curved on top of timber blocks varying in depths and glued to the blocks to stay in the shape.[17]

Principle and construction of type 3

Type 3 formwork is designed to cast the beams with wider web towards the ends. Thus the existing soffit formwork is required to change completely.[18]

The next pages contains a summary, through illustrations from Sang-Hoon Lee's dissertation, of the the development of the formwork principle and method of construction of the three formwork types.

matter… there's nothing more noble and elegant from an international viewpoint than resistance through form."

10 Chandler and Pedreschi, *Fabric Formwork*, 23.

11 As described in Pedreschi's lecture at ICFF2008; Ibid., 28. and Anne-Mette Manelius, *Flydende sten, Betons arkitektoniske potentialer. Et udredningsprojekt* (Copenhagen: RDAFASA, Center of Industrialized Architecture, 2007), fig. 71.

12 The underside of a part or component of a building (as in an overhang or staircase).

13 Sang-Hoon Lee, "Form-efficient Fabric-formed Beam," 54.

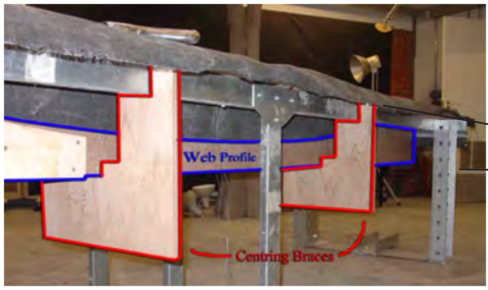
14 For detailed descriptions of the procedures, see Ibid., 160–177.

15 Ibid., 5.

16 Ibid., 160.

17 Ibid., 170.

PRINCIPLE AND CONSTRUCTION OF TYPE 1

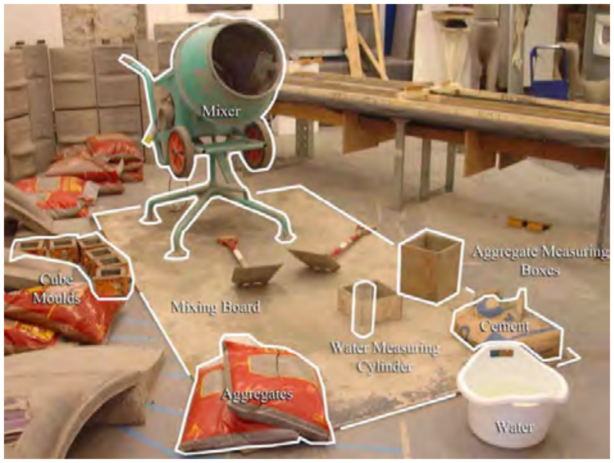


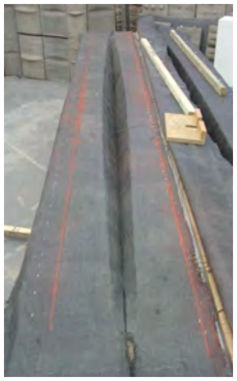
Left: Web profile is defined and cut in timber. It can be defined as a 'rigid seam'

Stencil frame (under fabric)

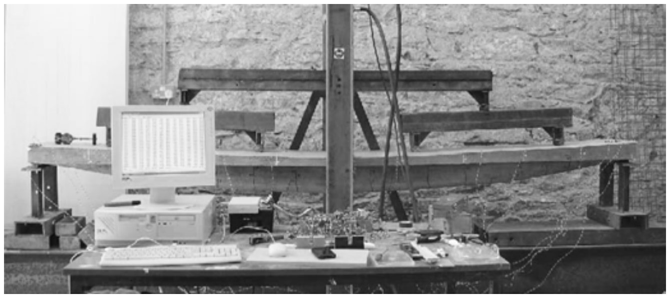
Rig

Setup for concrete mixing for Sang-Hoon Lee's thesis work. (Sang-Hoon Lee 2010, Fig 7-10)





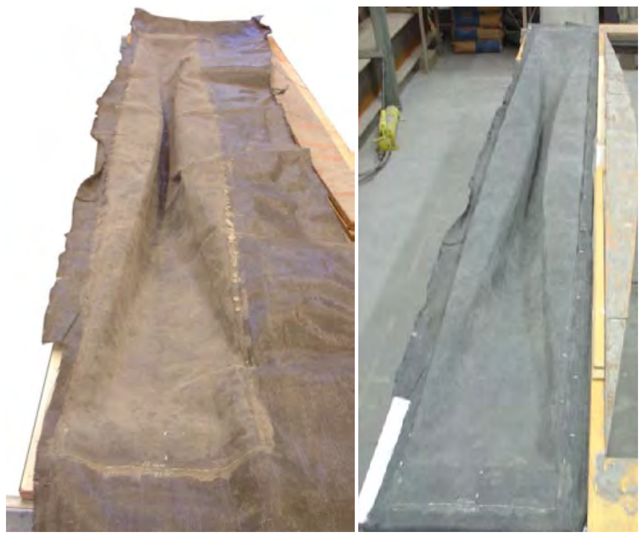
TYPE 2



Typical experimental setup from Sang-Hoon Lee's thesis work. (Sang-Hoon Lee 2010, Fig 5-20)

The formwork in Type 2 has an addition of a 'ridge' on the frame to make a parabolic curve. This increases the thickness at the supports (the ends of the beams)

TYPE 3



"In type 3 the timber pieces defining the web curve have been removed. Instead, the perimeters of the web are predetermined at sections and they are marked on the fabric. The part of fabric that is marked is dropped into the void of the soffit formwork and the rest of the fabric is stapled down. ." (Sang-Hoon Lee 2010, 174)

Left: The geometry of the web is predetermined in sections and marked on the textile. Right
When the fabric is securely fixed the rebar is placed on to the fabric. The rebar is no longer suspended at the mid-span from a wire but sits on a spacer, directly placed on the fabric. Thus it is the weight of rebar that stretches the fabric downward

The Stereogeneity of the Form-Efficient Beam

The stereogeneity of the beam is difficult to describe in full based on the images in the dissertation that document a process for scientific purposes with no attempts at conveying any tactile and sculptural qualities of the resulting concrete objects.

A description of the form and the structural type is simpler; the web and the flange share the stereogeneity of the single concrete element. The beam clearly appears as a structural element and *demands* a structural context, demands to span between supports and to be multiplied, with multiple identical beams placed side by side. This will double the width of flanges and create spaces between the web sections. In this way the beam can be placed in its context as a spanning architectural element that encloses and defines a space.

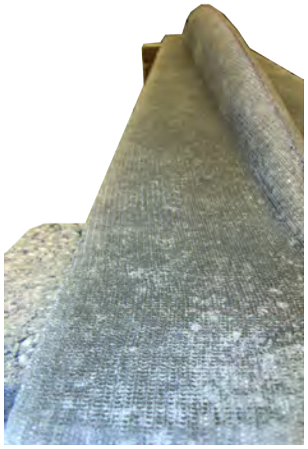
Roles of the Frame in the Form-Efficient Beam

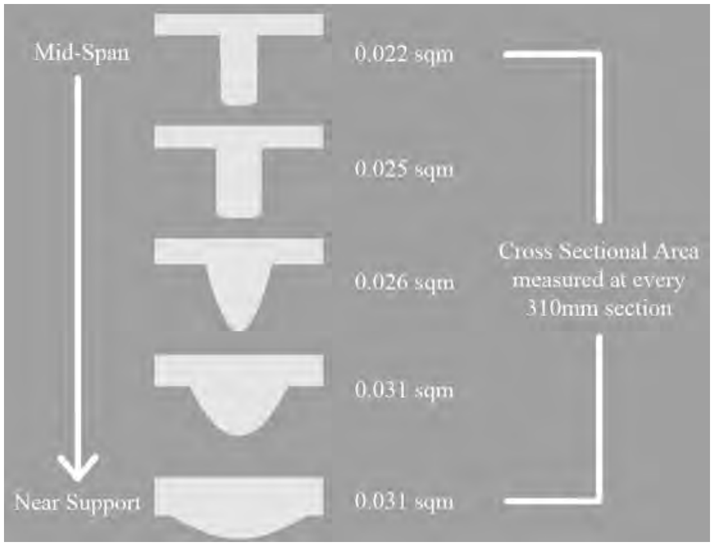
The whole process of developing the form-optimized concrete T-beam is an iterative process in which a digital program defines a certain geometry for the beam, and then Sang-Hoon Lee designs and constructs the physical fabric formwork, casts the beam, tests it and enters the data in the computer model to adjust the calculations for the optimum form.

Throughout Sang-Hoon Lee's thesis work, the framing principle has proven, with simple modifications, to form improved geometries for the concrete beam. Changing the formal or structural geometry of the concrete structure depending on its intended performance can be obtained through simple changes in the formwork frame. Changes included altering the two-dimensional cutting of the holes for the web profile in the plywood frame and varying the thickness of the flanges. Changes also occurred in regard to the placement and direction of the textile sheet, which affected the depth of the web as well as, more importantly, simpler formwork.[19]

The role of the frame in the formwork for the *Form-Efficient Beam* is similar to conventional concrete element production in which the frame can be defined as the structural boundary for the pour as well as the rhetorical definition of the boundaries of the architectural element. The 'floor' of the frame for the *Form-Efficient Beam* resembles a box to be filled[20] or the reversed coffer for a ceiling. This gives it an even closer resemblance to casting slabs, but a symmetrical figure is cut out of the bottom of the formwork panel. It is no longer a conventional, and the framing motif is altered as well. This may sound odd, but the frame of the *Form-Efficient Beam* can be understood rhetorically in a similar way to a stencil frame that is used to for spray-painting a pattern. Instead of paint on the surface within the stencil frame, the printing medium is concrete, and the impact is made on the membrane that bulges through the stencil frame.

This new notion of the *stencil frame* in fabric formwork can be understood as a *removal* of restraining material, and the cut plywood profile allows the fabric to bulge and deflect into the void when filled with concrete. This understanding of the frame *expands* its role as a restraint when the profile is cut to include the opposite notion of the *impacto*. The *impacto* is construed





Cross-sections of Type 3 Beam "11DADFWW12mm", (Sang-Hoon Lee 2010, fig 7-25)

The web geometry created by a 'rigid seam' keel results in a'knife-edge' detail. From formwork method for Type 1 or 2 Beam. (Photo: Lee)

and constructed as a stamp that presses against the bulging fabric surface; the rigid surface of the *stencil* frame does the same, but in this case the contour of the cut-out ensures a controlled release of concrete matter.

The major technical role of the framing principle in this experiment concerns the practicality of the fact that the plywood frame is easy to build and simple to adjust in order to modify the optimal formal geometry for the flange and the web of the T-beam.

When the iterative processes of tests and modifications have been completed, and the geometry of a specific form has been determined, the optimum formwork solution for multiple castings may not be the same as the one that generated the original form. As soon as *the* form-optimized shape is found, and it is to be applied in a structure, it may well be economically feasible to construct a rigid form for the purpose.

Conclusion

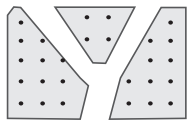
Despite its usefulness, fabric formwork may not, in all building cultures, be the most 'appropriate' alternative for producing big and identical beams in large numbers.[21] Nevertheless, the thesis work does indicate that the method used in developing the *Form-Efficient Beam* is simple to use in the development phase of adjusting and refining the geometry for form-optimized beams and for producing unique beams or decorative structures with advanced geometries.

The *stencil frame* is a formwork element that is tied to the notion of the rig[22] in the analytical study of the *Form-Efficient Beam*, and which is associated with prefabrication in a factory. The case features an element that is cast horizontally, and which explores the specific instrumental role of the *stencil frame* as an adaptive and forming restraining element in combination with a sheet of fabric stretched across the frame.

The specific frame principle can be recognized in practice of construction and architectural research as shown in the images on the next page. Decorative use for the stencil frame principle can be recognized in ornamental marks on furniture [Copenhagen Bench, TEK1 2010]. The side of the bench was cast vertically, however upside down. The *Y-shaped column* made at CAST can be described as constructed of two stencil frames clamped together. The little icon for the stencil frame is inspired by the iconic shape of this prototype illustrated on the next page.

The definition of the *stencil frame* in the *Form-Efficient Beam* complements the notion of the *impacto*.[23] Both of these formwork elements have technical *and* rhetorical roles, and thus the naming of the *stencil* frame takes on special significance in the forming of a vocabulary of formwork tectonics for fabric formwork.

Stencil grafitti. A stencil is used to mask an area; in street art, pigment is applied in the stencil hole. The stencil may be reused numerous times but little variations between 'tags' may occur during the application of pigment/paint



Stencil frame. The icon is inspired by a project made at CAST, which also applies this framing principle.

18 Ibid., 173.

19 The last example used a single sheet of fabric, where earlier versions had used two sheets of textile, defined and connected with a curved clamping device.

20 "Box," *The Cassell compact dictionary* (London: Cassell, 1998). A box is defined as a case adapted for holding solids, not liquids.

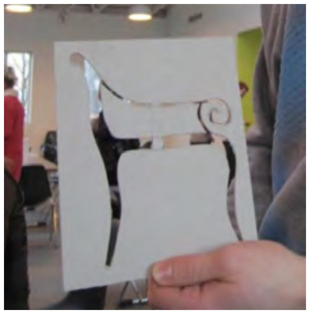
21 Appropriateness also includes aspects of economy. In a northern European context, the cost of labor is high and hence also the incentive for prefabrication. Responses from Danish contractors to Sang-Hoon Lee's work included that the formwork is interesting if it allows for simpler and cheaper production of existing types of concrete beams. Conversations referred to by Sang-Hoon Lee at fabric formwork seminar in June 2011, hosted by Diederik Veenendaal, ETH Zürich. The author's contractor colleagues at Pihl have also expressed natural reservations in regard to implementation, which will be addressed in the Perspectives chapter.

22 An underlying central theme in Pedreschi's experimental research/teaching at ESALA.

23 Developed at CAST. The roles of the impacto forms part of the analytical study of the dual-sided role of the form tie in the *Clamp Wall*.

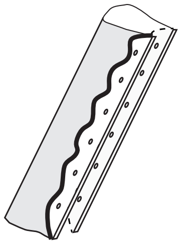
Stencil frame principle used for detail of platform on the Vergennes River Walk, Vermont by Sandy Lawton of Arro Design. 2011

Y-shaped column made at CAST in stencil frame

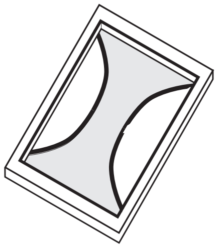


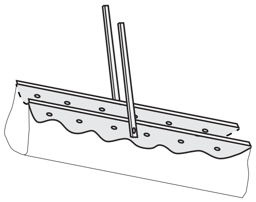
Stencil frame principle used for ornamental purposes, 'Copenhagen Bench' cast upside down, Student work, (Appendix 8.4)

POTENTIALS OF THE FRAME

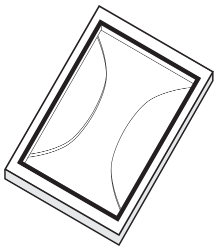


Stereogeneous
consequence





Structural principle



TECHNICAL AND SYMBOLIC POTENTIALS FOR THE FRAME

The technological roles for the *frame* in the context of fabric formwork have potentials when viewed in relation to the formwork principle for the individual component and in regard to a larger building system.

The analytical studies of *Sinus Column* and *Form-Efficient Beam* discussed the roles of the frame as part as the construction and construing of a single building element.

Findings from the studies include a concern for the notion and principle of *rigid seam* and of the *stencil frame*. Since instrumental roles of the frame cover the *rig, falsework* and the *bracing elements* within the frame, parts of these aspects will be briefly discussed here.

Rigid Seam

The frame of the *Sinus Column* was called *rigid seam* in the analytical study. The potential of the *frame* in the *Sinus Column* is to serve as the textile *seam* adapted to the scale and procedures of construction and as the vertical bracing device for the formwork structure. As discussed in the study [1] and quoted from Semper, the inherent rhetorical potential of any seam is to make a virtue out of necessity,[2] as a simple curvature cut in the bracing laths (the frame) is an articulation of the notion of the ornamental textile *seam*. Used in formwork for concrete, the *frame* used as *seam* has a direct stereogeneous consequence on the poured structure. This points toward an application of the frame as a clamping device, thus translating the tailoring procedure of the dart[3] to the architectural vocabulary for fabric formwork.

If we consider a point version of the *rigid seam*, it serves the technical bracing function of the frame as a clamping device.[4] If we define a seam as a linear connection , we can describe a rivet as a connection made in form of a point or a series of points. The point version of the *rigid seam* could thus be seen in light of Semper's comparison between the seam and the rivet[5] and labeled a *clamp rivet*. It should be noted that the device has the same ornamental potential as the *rigid seam*. This word, *clamp rivet*, is however rather clumsy and also self-contradictory in the sense that a rivet is permanent, while the clamp may be temporary. This points to the inherent dual-sided roles of the device but does not offer the immediate understanding of the ornamental potential and textile association that is inherent in the term *seam.*

Delanda's discussion about the Eskimos and their 29 terms for snow comes to mind.[6] This perspective makes it is clear that the descriptive term for this specific clamp will arrive objectively if or when the device has found an application in a structural formwork principle. For now, *clamp* (*rivet*) will have to do, and below follow a few thoughts on the technical application of it in fabric formwork.

Technically, the *clamp (rivet)* is important in regard to formwork applications that are more structurally complex than the simple column formwork structure.

As described in the *comparative/taxonomic table* the fabric formwork can be structurally *hung.*[7]

Frame Potentials as Part of a System

Aspects of a frame in a system cover the relations to other structural framing elements, as used on site for the *Vermont Wall,* or the concrete elements that are used as structural components in the built structure, such as other prefabricated concrete elements or building elements of other materials. The connections between these elements can either be concealed or highlighted, and the elements can be considered either interdependent or autonomous.

For the *Vermont Wall*, the connection between the formwork frames was enhanced by placing the frames apart and binding the framed textile elements with a literal seam, as the excess textile from each structural frame was rolled up and bound. During the pour, these spaces between frames formed pilasters (see image). In this sense, the articulation of the seam became an architectural element in itself.[8] A form of linear *impacto* would have been the stereogenous consequence if the formwork frames had been placed with no space in between. These linear impactos may act as crucial points to consider for building; if an internal wall is constructed against the fabric-formed concrete wall, it will be easy to affix other structural elements to the planar-linear surfaces.

The Stencil Frame in Construction

Daniel Sang-Hoon Lee has argued that fabric formwork can be used for cheaper construction of sculptural T-beams similar to those used in many of the Austrian architect Harry Seidler's projects.[9]

Lee has argued that the use of fabric formwork could have resulted in cheaper construction of the hundreds of large,[10] identical, serially produced beams. It is interesting to discuss the use of fabric formwork for form-efficient beams against Seidler's T-beams. Sang-Hoon Lee would like to use fabric formwork, a specific formwork technique, for a specific type of beam. Seidler's aim is the actual construction of the specific beam type. Seidler lets it be up to the contractor to decide on the production method.[11] He is interesting here, first of all because the structural shape of the T-beams are almost identical to the one developed using Lee's formwork.[12] And secondly because variations of Seidler's form-efficient T-beams have been produced for several projects.

T-beams by Harry Seidler

Harry Seidler had his roots in the New Bauhaus,[13] the fascination of contemporary artists[14] as well as the structural principles of the collaboration with Pier Luigi Nervi.[15] Seidler used characteristic T-beams in all his projects for office buildings, which required large free spans to allow an open plan. Different locations of his projects allowed for different construction solutions – it all came down to the price of construction, and the contractor was given the option of casting on site or using prefabricated elements.

In France the T-beams were produced as prefabricated pretensioned elements.[16] Sydney

1 The analytical study of the *Sinus Column*

2 Semper, *Style*, 153–7.

3 "Definition of 'Dart'," *Textile Glossary*, 2011, http://www.textile-glossary.com/terms/dart.html. [achieved 2011-10-06]. A sewn dart is a tuck in the fabric that is sewn. It is used to define the shape of a garment, making a two-dimensional piece of fabric into a three-dimensional garment. Darts are usually seen in clothing where the body curves: bust, waist, hip.

4 *The Cassell Compact Dictionary* (London: Cassell, 1998), sec. Clamp. Clamp *n.* is 1:a frame with two tightening screws to hold pieces of wood etc. together, 2: a piece of timber or iron used to fasten things together.

5 Semper, *Style*, 157–8. Semper sees a linguistic and conceptual similarity between the seam (*Naht*) and the rivet (*Niehte*) and emphasizes his theory of dressing (*Bekleidung)* in architecture through an analogous description of buttons and embroidered seams to fasten connecting clothing parts.

6 Manuel DeLanda, "Material Evolvability and Variability," in *The Architecture of Variation - Research & Design* (Thames & Hudson, 2009), 7. The discussion of poetic variation in a language as a qualitative objectivity is relevant here.

7 Self-stressing textile

8 Note about the significance of the space between elements in Utzon's Espansiva project

9 Sang-Hoon Lee, "Form-efficient Fabric-formed Beam," 157. The T-beams used for example in Hong Kong Club Building (1980-84 in Hong Kong Central) and in Harry Seidler Offices and Apartments (1973-94, in Sydney).

10 Kenneth Frampton and Philip Drew, eds., *Harry Seidler: Four Decades of Architecture* (Thames and Hudson, 1992). 11 x 2.4 m for the office building and 17-meter spans for the Hong Kong Club,

11 Ibid., 201. "… *We gave the builder the choice to precast the structure. He chose to pour-in-place but used a mechanised system of plastic formwork which resulted in a continuous, organically more expressive strucutral form*…" says Seidler about the construction of Navy Weapons Workshop

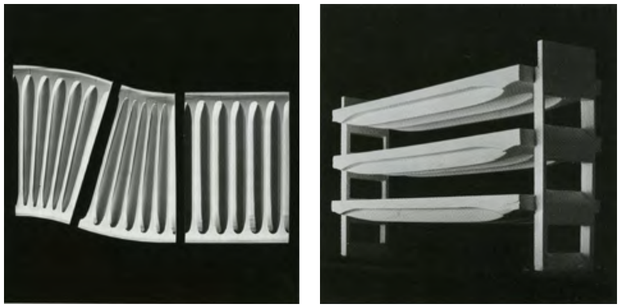
12 Sang-Hoon Lee, "Form-efficient Fabric-formed Beam," 156–58. this is also pointed out by Lee.

13 Philip Drew, "1945-1976: The Migration of an Idea," in *Harry Seidler: Four Decades of Architecture*, ed. Kenneth Frampton (Thames and Hudson, 1992), 17. Drew cites Walter Gropius for the intention to introduce a method of approach which allows one to tackle a problem according to its peculiar conditions.

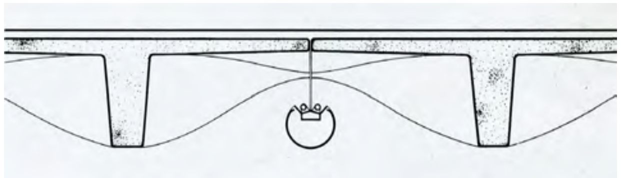
14 Ibid., 28. For example Frank Stella as well as the modular constructivist artist Norman Carlberg, with whom Seidler shared an interest in exploring the structural potentials of working with only a few geometrical elements.

(Notes continue after next spread)

Ribbed concrete ceiling by Nervi's successor Mario Desideri and sculpture by Norman Carlberg. Harry Seidler: Riverside Development Stage 1, Brisbane (1983-86) (Drew and Frampton, 266)



Principle model using prestressed T-sectioned elements. (Drew and Framton, 89)



Section showing suspension of tubes for air-conditioning and lighting strips beneath precast elements. Harry Seidler Offices, Milsons Point, Australia (1971-73) (Drew and Framton, 322)

14.5-meter-spanning T-beams were produced on site, cast in sections of mass-produced glass fiber-molds.[17]

In Hong Kong the low cost of labor meant that the formwork for the T-beams was built on site.[18]

The point is that the right formwork method depends on a number of factors that are specific for each project.

A different approach to discuss the implementation of the formwork would be to dissolve the specific application of Lee's *form-efficient beam*. Instead the *stencil frame principle* takes on more prominence as a type element.

Ribboned Floor Cast in Stencil Frame

Sang-Hoon Lee's stencil frame could then be used to cast a 'ribboned' floor on site in a method that brings a reversed understanding of the 1934 patent of Waller to mind.[19] Using Waller's method permanent beams could support a formwork membrane and the subsequent concrete floor. A stencil frame support based on the present formwork method would instead create the soffits. Beams (the web of T-beams) would be the bulges created between supports.

This could be an option in a low-tech environment because it holds certain benefits. The concrete structure is lighter with the form-optimized beam, and less concrete is needed; expenses for a crane to handle heavy concrete elements are eliminated. Versions of stencil frames or soffit impactos between the webs can be prefabricated, and they also function as the supporting falsework for the formwork for the deck.

Revitalize Concrete Typologies

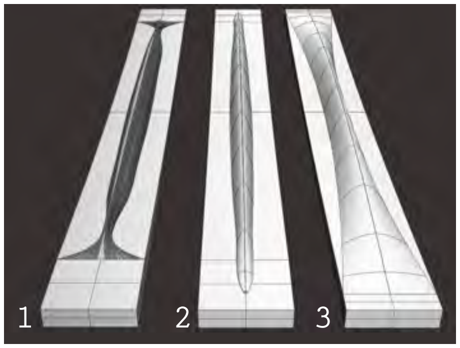
Response to Sang-Hoon Lee's fabric-formed beams from Danish contractors[20] indicates that interest will emerge if the method results in cheaper production of the elements they already produce.[21] Perhaps the difficulty for the appreciation and implementation of the form-optimized beam is that the T-beam is a similar concrete element that is already being produced and handled very rationally with traditional methods; the dimensioning and production of formwork for beams with rectangular webs are simple to adjust in length, width and depth, and concrete beams with rectangular contours are simple to stack in layers on a truck.

Instead of competing with an existing typology, one might consider the future for form-optimized concrete element that could benefit from being produced in fabric formwork or which could only be produced in fabric formwork. In such a case one would not have to compete on price, because it would be possible to offer the production of structures that are not currently on the market.

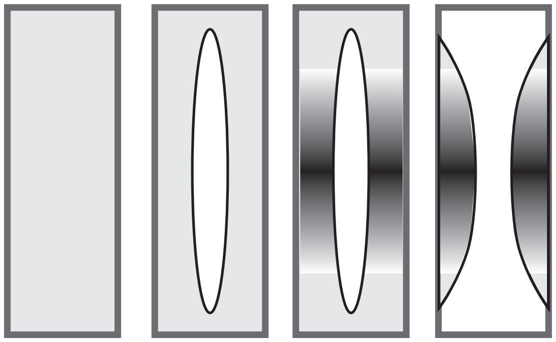
The construction technique developed for the *Form-Efficient Beam* may simply benefit from being applied to more complex form-efficient structures such as Nervi's so-called isostatic ceil-

Left section of images: images of the on site construction of T-beams for Navy Weapon Workshop by Harry Seidler (1980-85) (Frampton and Drew 1992, 197).
Right section of images: Details and construction of prefabricated T-beams for Australian Embassy, Paris, France (1973-77) (Ibid. 170).

The development of the frame from 'flat bed' to three types of stencil frame in the case. Stencils 2 and 3 have increased thickness on the middle

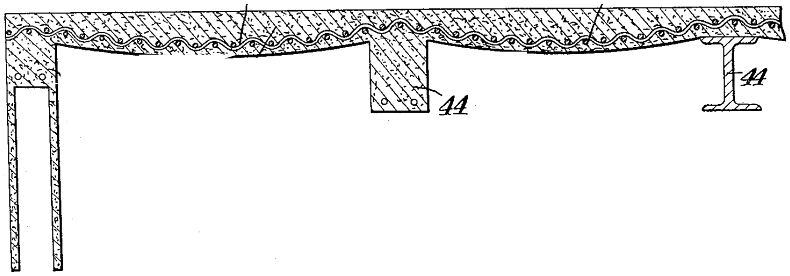


Form-Optimized Fabric-formed Concrete Beams

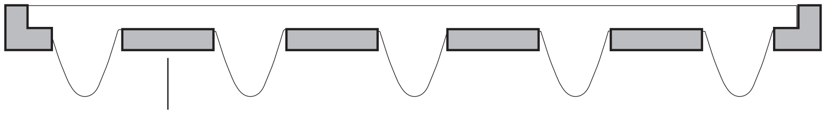


Flat | Type 1 stencil | Type 2 stencil | Type 3 stencil

Fabric-formed construction patented by James Waller. Suspended fabric as well as the concrete floor is supported by joists (44) (Waller 1934)

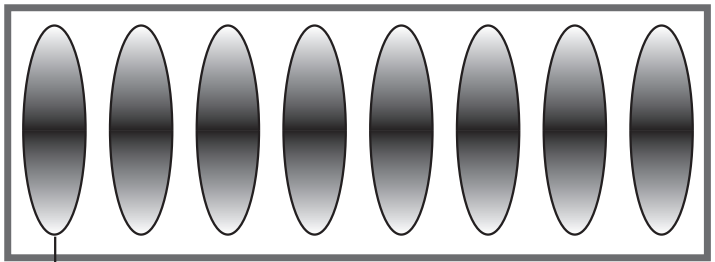


Section of formwork principle for a ribboned floor cast in stencil-formed fabric.



Stencil frame element

Plan of formwork principle for a ribboned floor cast in stencil-formed fabric.Individually the stencil frames are impactos. For a deck, the formwork elements should be understood as one strucutral surface elements, a stencil frame.



Stencil frame element

ings. The principle was a variation of his method of 'structural prefabrication.' It uses prefabricated reusable formwork to produce decks with 'iso-static ribs' that indicated the placement of reinforcement.[22] These structures can be described as webs and soffits of a more advanced composition than the ribbon ceiling previously discussed.

Lightweight and partly prefabricated, both versions of Nervi's system were still labor-intensive. Increasing costs of labor in combination with the increasing use of steel as formwork and as structural principle as well as a general shift toward more standard elements and lightweight construction may be the reasons for the decline of the use of Nervi's method.

An example of a revitalization of form-optimized concrete structures can be seen in research through design at the Aarhus School of Architecture (AAA), Denmark. Here, researchers[23] used a digital optimization program to develop a structural form that resembles Nervi's isostatic principles. The formwork appears less optimized, as the form was then CNC- milled out of polystyrene blocks.

The built concrete prototype has not been tested whether the form in fact is optimized. It would make sense to use simpler ways of producing formwork for such concrete structures that should run through series of empirical testing and modifications. In the built prototype the promise of form-optimization by a digital optimization program meets the reality of physical materials and construction. Furthermore, material-optimization could also include a broader understanding of material and construction economy.

The combination of the easily adjustable stencil frame with a membrane as formwork may make it feasible to produce full-scale mock-ups for preliminary testing and development for specialty structural slabs or elements. Such research could supplement investigations of construction methods for topologically optimized structures.

While the role discussed here of the rigid *stencil frame* element has several clear applications, the role of the textile element in these proposals is challenged. The problem is that the control of a specific web-geometry is dependent on the control of the fabric. This means that the fabric for a ribboned or iso-static deck is not a simple suspended sheet but in fact a surface with varied degrees of tension. A solution could be that custom-fabrics are fabricated for such formwork, an interesting topic for future research collaborations at the newly merged schools of Architecture and Design the RDAFASA.

Non-Potential for Form-Efficient Beam

Inspired by the difference between to *have* (generic) potential and to *be* potential (*actual potentiality*), the construction method *is* potentially forming a concrete beam. With the wide understanding in the present dissertation of concrete as conditions between liquid and solid, the role of fabric-formwork is not necessarily restricted as the forming method during the construction of concrete structures. Instead a particular potential of fabric-forming can be located in preceding development processes. The geometry of the beam is thus fabric-formed but the final mold may be rigid.

15 Kenneth Frampton, "1965-1991: Isostatic Architecture," in *Harry Seidler: Four Decades of Architecture*, ed. Philip Drew (Thames and Hudson, 1992), 87. Decades of collaboration between Nervi and Seidler were initiated in 1963.

16 Frampton and Drew, *Harry Seidler*, 154–71. Australian Embassy, Paris, France 1973-77.

17 Ibid., 194–202. Navy Weapons Workshop, Garden Island, Sydney (1980-85).

18 Ibid., 206–217. Hong Kong Club and Office Building, Hong Kong, 1980-84.

19 This was introduced in the Fabric Formwork chapter

20 Lee expressed this reflection at the Fabric Formwork workshop May 16-17 2011, at ETH, Zürich hosted by Diederik Veenendaal of the Block Research Group

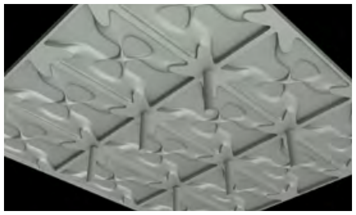
21 Such as pre-tensioned, rectangular L-, T-, and TT-beams.

22 For example for the Gatti Wool Factory in Rome, Italy, 1951.

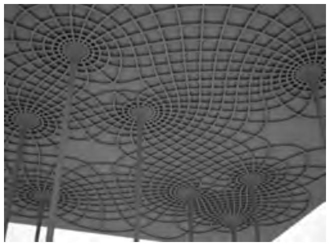
23 Per Dombernowsky and Asbjørn Søndergaard, "Three-dimensional topology optimisation in architectural and structural design of concrete structures," in *Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009* (Universidad Politecnica de Valencia, Spain, 2009), http://fluxstructures.net. Engineer, Ass. Professor Per Dombernowsky and architect Asbjørn Søndergaard made the prototype as part of the *Unika Beton*, (Unique Concrete) 2007-2010 project funded by the Danish National Advanced Technology Foundation with academic and industrial collaboration. "Unikabeton, Robotter, beton og arkitektur," *Unika beton*, 2011, http://www.unikabeton.dk/.

24 This aspect of form-making and mold construction is the subject of *Fabric-Formed Rigid Mold*, CAST, in the analytical studies of the textile element.

Images of a prototype of a form-optimized concrete structure. Unika Beton. Authors are Per Dombernowski and Asbjørn Søndergaard, Aarhus School of Architecture (2010).



Renderings by Søndergaard and Dombernowski of ceiling structure of combined form-optimized deck elements. the image resembles form-optimization work by Pier Luigi Nervi

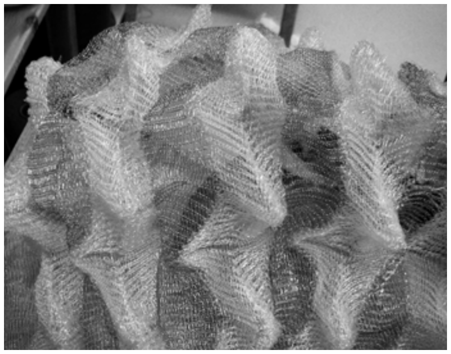


Right: Pier Luig Nervi used these 'lines of force' in the reinforcement pattern for the ceiling of his Gatti Wool Mill.
Above: similar lines of forces applied with a calculation with irregular arrangement of supports - from the essay "Rheotomic Surfaces" by the English architect Daniel Piker. (Piker 2009)

The opportunity to question how the material may *not* be used offers a different way of categorizing findings and locating additional potentialities between different 'conditions' of concrete's forming and construction.

Prefabrication of structural concrete elements includes a phase of form-giving and testing and a subsequent production phase. Sang-Hoon Lee argues that the method for the *Form-Optimized Beam* covers both the design phase and the production phase. The comparative discussion of the work by Harry Seidler indicates that the appropriateness of any construction method varies with locations and contexts but depends primarily on ease and cost efficiency.
The *stencil frame* may be one method among several possible procedures.[24]

So, if it is not the argument of cheap construction that seems plausible to contractors, it may instead be suggested that the formwork and testing method developed by Daniel Sang-Hoon Lee can be used as a design method in early stages of testing and developing structures. This notion suggests that the *stencil frame* can have a role as an addition to the existing formwork vocabulary for conventional industrialized construction.
The role of a lightweight formwork membrane may then, subsequently, enter into later stages of construction.



3D knitted textile with metal and polyolefin fibers. Image of textile sample from the workshop at the Borås School of Textile, Sweden. (AMM)

24 This aspect of form-making and mold-construction is the subject of *Fabric-Formed Rigid Mold*, CAST, in analytical studies of the textile element.

ANALYTICAL STUDIES OF THE FORM TIE

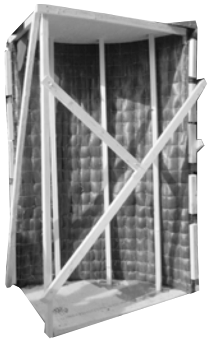
INTRODUCTION TO THE FORM TIE

ANALYTICAL STUDY OF THE CLAMP WALL

ANALYTICAL STUDY OF THE NET WALL

POTENTIALS OF THE FORM TIE

Clamp Wall



Net Wall

TYPOLOGY	TITLE	PARTICULAR FORMWORK ELEMENT	CONTEXT
COLUMN	Sinus Column	FRAME	CAST, Exhibition 2007
COLUMN	Composite Column	TEXTILE	PhD, TEK1, 2010
BEAM	Form-Efficient Beam	FRAME	PhD, ESALA 2007-10
WALL	Clamp Wall	FORM TIE	TEK1, 2009
WALL	Net Wall	FORM TIE	TEK1, 2010
SHELL	Fabric-Formed Rigid Mold	TEXTILE	CAST 2009
SCULPTURE	Ambiguous Chair	TEXTILE	PhD, Exhibition 2009

INTRODUCTION TO THE FORM TIE

In the comparative study/taxonomy, the term restraint was chosen to describe the principles devised to keep the suspended textile in place in specific points and surfaces.

The term was derived from a prerequisite for tensioned fabric formwork about which Mark West has said in numerous lectures that there is no tension without compression. This almost banal statement reminds us of a crucial point concerning the condition of flexibility*:* there is no such thing as flexibility without some sort of restraint. In other words, we cannot talk about flexibility in a material without defining the restraining factors surrounding it, suspending it, influencing or enabling it. The frame investigated in the previous chapter is one restraining agent; the *form tie* is another.

Both formwork elements enable textile principles to act and be exploited during pouring with the influence of wet concrete.

The restrictive definition of the word *restrain* as *holding back, keeping under control, confining*[1] is one reason for changing the term for the purpose of locating additional rhetorical qualities in relation to the technical role of the clamp of keeping the formwork under control.

In the context of formwork, the verb to *tie* has a similar technical definition to restraint: to bind, fasten, restrict; the act of tying a bow also indicates forming.[2] This aspect *adds* possibilities to the technical role of the clamp; the form tie thus potentially ties the formwork and gives it form.

The form tie as knot

How can the role of the form tie in fabric formwork form the basis of analytical studies? Considering the form tie related to Semper's understanding of the knot as the oldest technical symbol allows an understanding of a net as a system of knots.[3]

The examples to be studied in the following are sculptural explorations of the construction of a concrete wall element cast in fabric formwork. The restraining systems of the *Clamp Wall* and the *Net Wall* represent the knot and the net.

The notion and principle of the form tie have two different points of departure. The *Clamp Wall* departs from the notion and principle of the quilt-point-clamp to ensure maximum thickness of the wall and the *Net Wall* is the development of a restraining system based on a workable character of metal netting.

Questions framing the studies

What is the relationship between the rhetorical and technical roles of the form tie as knot or as net, i.e. a series of knots?

Does the use of the form tie add new textile 'layers' of understanding to concrete architecture. It could be hypothesized that there is a whole new range of form-tying principles waiting to be labeled, and that these principles will show textile features translated to concreting.

Since the restraining principle in fabric formwork has a direct stereogeneous consequence on the concrete form and surface it can already be asserted that the role of the form tie in formwork is bound to take on increased architectural potential.

What is the significance of the point clamp in the experimental case of the *Clamp Wall,* and how can the technological roles of the restraining net in the *Net Wall* be interpreted in order to inform the formulation of the potentials of the form tie in a formwork-tectonic vocabulary?

1 *Cassell Compact Dictionary*, restrain.

2 Ibid., tie.

3 Semper, *Style*, 219–220.

STUDY OF THE CLAMP WALL

Students: Katrine Dilling Holst, Magnus Maarbjerg, Iris Laxdal, Viktor Harald, Andreas Pilavachi Osterheld, and Rebecca Nakayama Karstens

Where: RDAFASA

Year: 2009

Context: TEK1 Workshop

STUDY OF THE CLAMP WALL

Structural typology of concrete	Wall
Structural typology of formwork	Frame with prestressed fabric
Role of fabric in formwork	Embraced
Reinforcement:	French bolts screwed into the plywood base
Concrete type:	Small aggregate, 4-8 mm
Concrete procedure:	Pour (from truck)
Short description of formwork principle	200 cm free-standing wall with three straight edges, standing on a curved edge. Square clamps act as form-givers and structural re-straints act

Q

Image of square form tie, left

The *Clamp Wall* explores a unique feature in fabric formwork: the direct formal consequence of the restraints upon the responsive formwork. The question with regard to the instrumental and rhetorical roles of the formwork element could hardly be any clearer.

Are there certain textile features that are enhanced by the example of the use of form ties in the experiment, and how is the conventional technical role of the clamp developed as *form tie* in formwork construction?

The concrete piece is 2 meters high and 1.3 meters long. It is a wall with three rectangular sides and one S-shaped side. The wall has horizontal rows of square *impactos* marks, a few impactos on the top row and an increasing number going down. The surface bulges and creases in between the marks. There is less bulging on top and more at the bottom.

The surface has imprints of textile and plastic-lined holes as well as clamp holes that penetrate the element in the center of the square impactos.

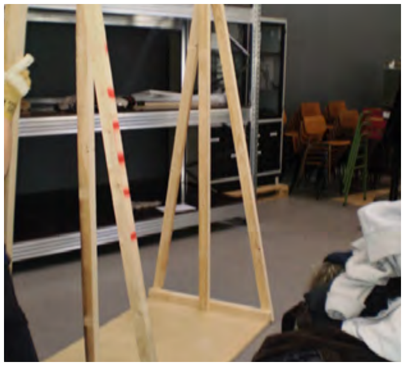
The two vertical sides are slender, approximately 5 cm. The straight sides carry imprints from a piece of wood. The top has a rigid horizontal mark. The concrete piece stands on a EuroPallet.

The context of the Clamp Wall

The cultural context of the experiment was the TEK1 Concrete Workshop[1] in 2009 with the title *"Sharp Edges / Soft Curves;"* the sharp and the soft referring to the stereogeneous consequences of textiles and rigid formwork elements used together in formwork. In the workshop, groups of students were assigned to construe and construct a concrete piece that explored the properties and formal consequence of using rigid plywood and flexible textile sheets.

1 60 second-semester architecture students participated in the workshop as part of the mandatory course TEK1 for first-year students of architecture at the academy, in 2009. The workshop was planned and taught in collaboration with fellow researchers Architectarchitect, Industrial PhD student Johannes Rauff Greisen and engineer, Ass. Professor Finn Bach. See the appendix/2 for the brief and summary of all student work.

Clamp Wall has three straight edges and one curved.The number of form ties reflects the formwork pressure as well as the amount of surface; the witdh of the textile was longer in the bottom.
The writing in white was transferred from the exterior of the formwork.









Images of the construction of the formwork structure for Clamp Wall, page excerpt from the report

In order to ensure a 'clean slate', introductory lectures given prior to the workshop only offered very few references to the state of the art of fabric forming.

The wall and part of the formwork were later exhibited.[2]

The specific form tie principle used in the experiment

The students used a *quilt point method* as the restraining method, where a clamp connects the two textile sides of the formwork. The method makes it possible to place the form ties freely on the textile surface.

The students were introduced to an application of the quilt-point method with an even distribution of clamps in the UEC construction system[3] and the experimental placement of clamps in *Wall One*.[4]

The structural formwork principle applied in the Clamp Wall

The structural formwork principle is based on a formal aim for the wall structure: The students had the aim of producing a self-standing wall with the same slender thickness, 5 cm, throughout as a fully controlled shape with three straight edges and one free-formed edge. They wanted to produce a concrete structure that could only be cast in fabric formwork.

Early sketches display the textile as a draped curtain and as an upholstered mattress with quilt-points and bulges.

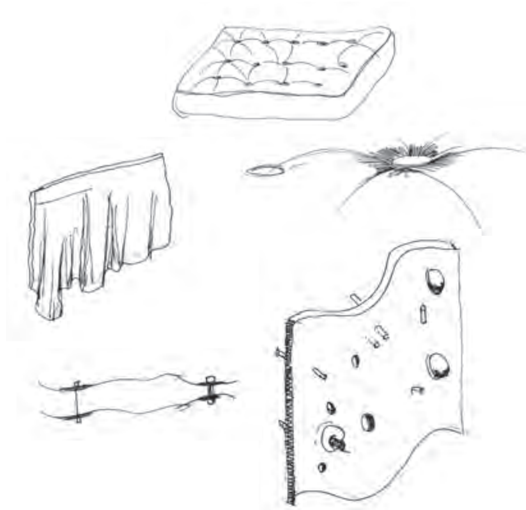
The formwork principle is based on the edges of the concrete element; the framing of the textile defines the extent and the geometry of the concrete element in the sense that height, width and the 'draped' free-formed curvature is outlined by rigid formwork elements. The form tie is the sculptural tool, and ties are to be placed to form an ornamental pattern.

Construction of the Clamp Wall

The frame was constructed, and the textile mounted and tensioned, moving out from the middle. The rig was further reinforced to survive handling and transport.[6]

- The textile is cut like a trapezoid; it is wider at the bottom in order to follow the curvature of the bottom rig, and shortest at the top where the frame is straight. There was a shortage of geotextile, so several pieces were connected by sewing and double-sided tape.
- Clamps are prepared; 7 cm distance tubes, 10 x 10 cm impacto discs from 12 mm plywood, and screws. The square impactos were the simplest to produce at the workshop.
- One side of formwork is mounted and form ties are placed. Form ties and the textile are connected carefully because the spacer tubes have to stay between formwork sheets.
- The formwork structure was filled with concrete delivered by truck. The group used left over laths with a protective layer of bubble wrap to compact the concrete around the form ties.[7]

Left: regular placement of quilt-point clamps. Kenzo Unno (West 2007).[5] Right: experimental placement of clamps, Wall One (Chandler & Pedreschi 2007)



Prelimenary sketches, from the student report

2 Scandbuild, "Trade Fair 2009." With the *Ambiguous* Chair and fabric-formed concrete tests from the diploma work of Sørensen and Wonsild, which AMM co-supervised.

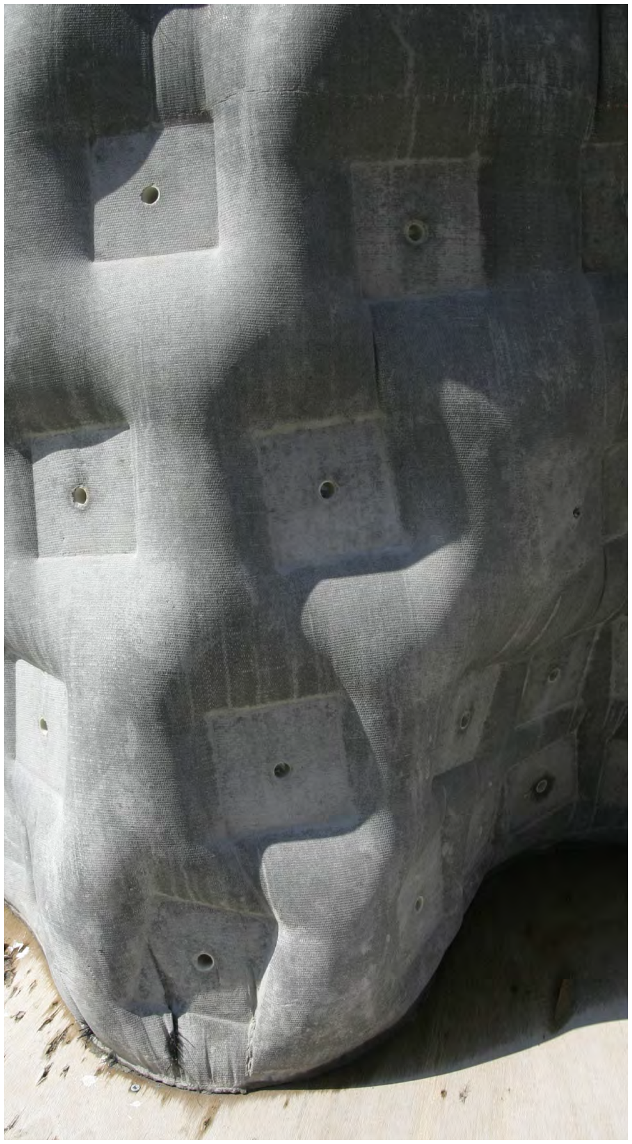
3 By the Japanese architect Kenzo Unno.

4 Aspects and illustrations of the workshop wall are present in most chapters of Chandler, Alan and Pedreschi, *Fabric Formwork*.

5 West, "Kenzo Unno."

6 The construction part of the workshop took place at the Technical University of Denmark in Lyngby, and subsequently the formwork structures were transported by truck to the Royal Danish Academy of Fine Arts, School of Architecture, where the other segments of the workshop took place.

7 As instructed by the author, inspired by the practice of URC.



STEREOGENEITY OF THE CLAMP WALL

The piece appears with a contrast accommodated by impactos formed by rigid formwork elements, the frame and the square impactos, and the bulging curvature between the impactos.

The impactos are recognized as square and identical, and they are interrelated in a system, yet at first sight their placement may appear random. The identical dimensions of the squares act as a type of measuring tool that enhances the understanding of the overall geometry of the wall. The impactos appear to be positioned at equidistant intervals; yet in fact there are nine impactos in the bottom row and only three in the top; this indicates that fact that the surface is wider at the bottom than in the top.

The surface has a clear imprint of the weave of the geotextile, and the quality of the concrete appears even, with a minimal number of blowholes. Tiny creases appear here and there, and the stitches from sewing the textiles together were embedded into the concrete along with fibers from the end of one of the textile sheets.

The students were surprised to find an exact transfer to the concrete surface of a goofy statement painted with white form oil on the exterior side of the textile form– the oil had altered the permeability of the textile and the writing was transferred directly to the concrete surface to stay there for good.[8]

Traces of all the formwork elements appear on the concrete structure and clearly express the *ginomai* of the *Clamp Wall:* The rectilinear frame and impactos and the textile as well as the rapid pouring procedure of the concreting are evident.[9] Eduard Sekler would call it tectonic.

Roles of the form tie in the Clamp Wall

The instrumental role of the form ties was to restrain the fabric from bulging. Square *impactos* were the geometric shape that was the easiest to produce with the tools available.
The round washers of the quilt-point method signify a point; the square introduces a direction and thus the opportunity to play with the position of the impacto; in fact one could describe this kind of form ties as *impacto form ties*. Thus, in this set-up, the geometry and placement of the square impactos is given a rhetorical role as ornament.

As mentioned earlier, the formwork structure for *Clamp Wall* has all its tectonic elements in play; the *frame*, the *textile* and the *form* ties and all the elements have important relations. *What demands does it place on the complimentary formwork elements* when the form ties are given full flexibility and can placed freely?

In order for the form tie points to be placed 'freely' there has to be a surface to follow – the overall surface of the Clamp Wall piece is defined as tensioned between the four sides of the frame.

Discussion of construction

The curious transfer of print from the exterior of the formwork to a permanent mark on the concrete surface has potentials and also demonstrates some of the challenges for the implementation of the principle in construction. Printing on the exterior surface of geotextiles can provide new ways of exploring decorative concrete surfaces. If permanent marks are undesired, chalk could be used as temporary marks during construction.

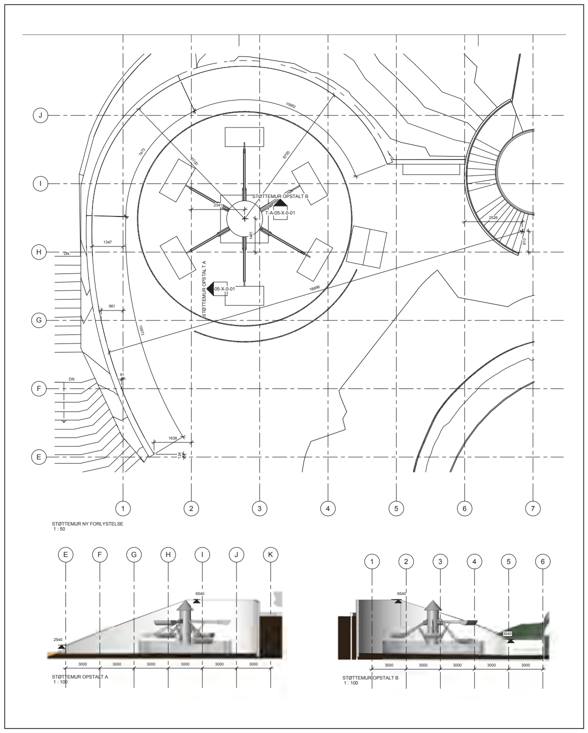
Left: filling the mold and compacting externally with 'pokers'; right, striking the formwork (images from the report)

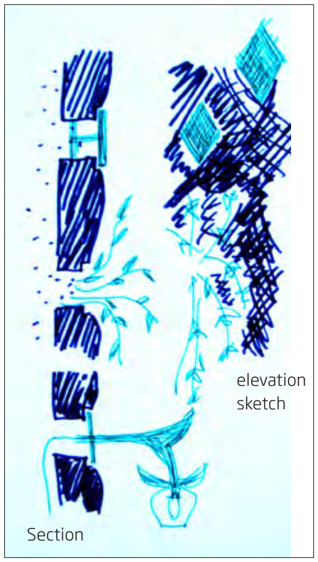
8 The writing was still visible in August 2011, two and a half years after the workshop.

9 A slower pour would have caused a lower formwork pressure and smaller differences in the bulging surface.

PROPOSAL FOR WALL IN THE TIVOLI GARDENS

By the Author





Poster for Tivoli Gardens

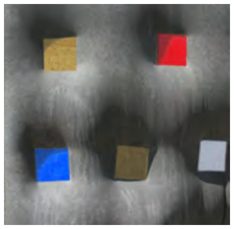
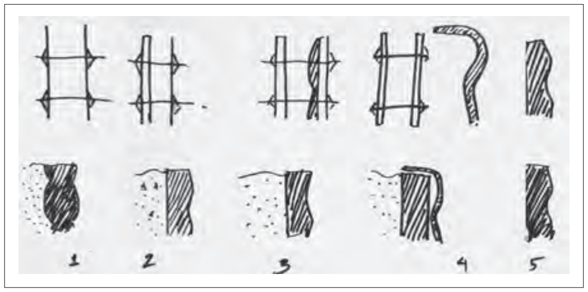


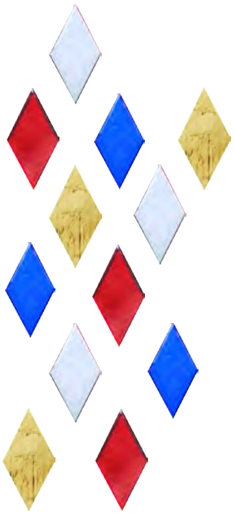
Illustration that uses the *Clamp Wall* to illustrate how tiles cover the impacto marks or block.outs on the wall.

Above:Sketches that show functional 'impacto-block-outs' as either covered with tile (top), used for planting (middle), and used for light fixture (bottom left).

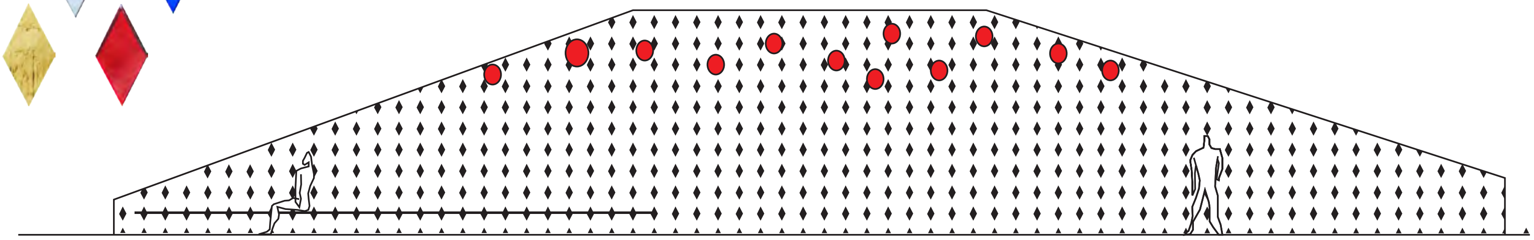
Top middle: The retaining wall by the 'Rasmus Klump' playground will be 30 meters long and 0.5-5 meters high. The wall will support shift in the terrain of over 4 meter. Behind the wall is the Tivoli castle and an exit to the street (H.C. Andersens Boulevard). Drawing by Tivoli Architects.



Left:Sketches of principles to make the concrete wall, 1. Double-sided fabric formwork (FF) 2. One-sided FF 3. Rigid formwork with inlay 4. Rigid formwork with 'dressing' 5. Prefabricated FF-element



Below: Unfolded elevation for Tivoli Wall (2010) with lanterns. Rhomboid impacto marks was suggested covered with reflective tiles.



CONCLUSION

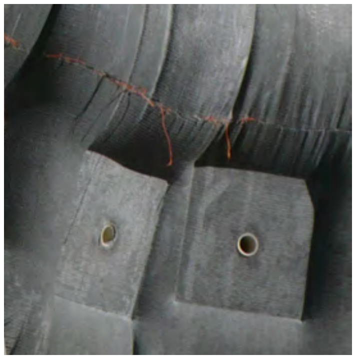
The direct stereogeneous consequence for the design and application of the form tie in fabric formwork displays equal degrees of instrumental and rhetorical significance.
If the gridded concrete surface cast using the quilt-point method[10] illustrates degrees of repeatability and rationality of a construction element in construction, the *Clamp Wall* displays a focus on the sculptural potential of the clamp itself. The square geometry is part of this.

The experiment shows a curved wall with clamps of identical depth. Shorter or longer 'clamp tubes' will allow the maker to vary the thickness of the wall.

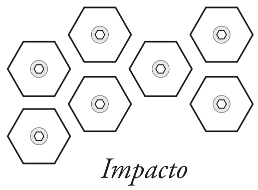
The form tie is a conventional formwork element that displays an increased (rhetorical) form-giving potential in the construing and construction of fabric formed walls. This is a potential that could be developed in order to strengthen the material appearance or aesthetics of fabric formwork. The impacto form tie offers great formal freedom and requires an equally large degree of accuracy to fulfill its rhetorical and instrumental roles.

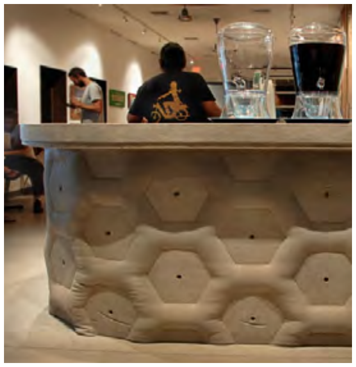
The author was invited to collaborate with the house arhitects of Tivoli Gardens for a construction of a retaining wall to surround a new ride in the amusement park. The principle of the impacto form tie was suggested by AMM used in a proposal during the thesis work. See the previous page for a visual summary.

The writing on the surface is still visible, June 2011



Sticthes and fibers embedded in the concrete surface, image taken at Scandbuild, March 2009





Left, icon for impacto inspired by the hexagon impactos for a fabric-formed interior of a restaurant. Gore Design, Arizona, USA, 2011 (www.goredesignco.com)

10 For example Kenzo Unno, *"URC house with grass,"* Architecture, House, built for Eiji Hoshino, 2003, described in West "Kenzo Unno."

STUDY OF THE NET WALL

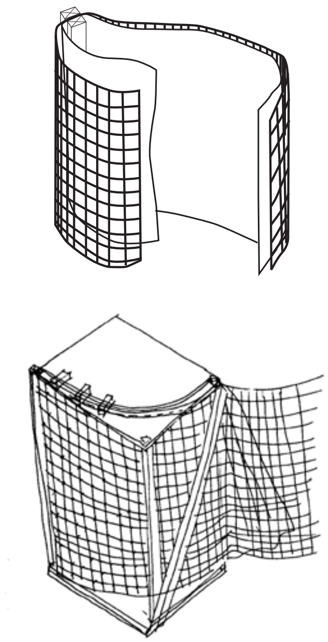
Students: Siri Reisæter Rasmussen, Astrid Asmussen, Rasmus Gosvig, and Christian Bencke Nielsen

Year 2010

Context: TEK1 Workshop

Structural typology of concrete:	Wall
Structural typology of formwork:	Frame
Role of fabric in formwork:	Embraced
Structural restraint of formwork:	Net and ties
Formwork construction:	Prefab
Reinforcement:	6 vertical 6-mm rebars
Concrete type:	Small aggregate, 4-8 mm, poured from truck
Short description	Embracing net as a 'stiff textile' is used as the conceptual form-giver and the major structural formwork element as a 'soft lattice'.

Ed



Net Wall: The formwork principle of the 'embracing' net and the embraced textile membrane.

The *Net Wall*[1] is a 2-meter tall curved wall slab cast on a EuroPallet. The concrete surface appears with bulges between the grid pattern of a 10 x 10-cm metal garden fencing net. The bulges correspond to the pattern of the restraining net and the form-tying pattern applied to it.
The restraining element for Net Wall consists of a system of Net and Ties. *What are their roles, as rhetorical and instrumental signifiers of concrete construction, and how does the analytical study add nuances to the vocabulary of the tectonics of fabric formwork*?

The title of the TEK1, 2010 concrete workshop was *Element and Connection*. Element referred to the individual elements created by the group, while the *connection* referred to the architectural and physical connection between the elements; this theme did not evolve further to a great extent[2] and instead the theme of the (wall) element remained in focus.

Groups of students were assigned to construe and construct the formwork principle for a 2-meter high slab across a EuroPallet, using a maximum of 250 liters of concrete.

Structural formwork principle for the Net Wall

The formwork principle is a tall, curved, slender structure formed by a metal net around an inner textile membrane that contains the poured concrete. The formwork pressure will push the textile through the openings of the restraining net and create soft-looking concrete bulges determined by the pattern of the net.

The student group made two rules to guide their work: The formwork must only consist of some form of a net, and there should be no perforation of the formwork by bolts or otherwise.

The design rules for the principle were modified during the experimental process. In the constructed formwork, nets are tied together to resist the formwork pressure, the tying pattern following the anticipated changes in hydrostatic pressure; in other words, there were more ties at the bottom and fewer at the top of the formwork structure.

The specific net used for the *Net Wall* is a 10 x 10-cm garden fence made of galvanized steel of approximately 1-mm thickness, a kind that is widely available at local building supply stores in Denmark. The dimensions (120 cm wide) fit the width of the concrete structure.

Construction of the Net Wall

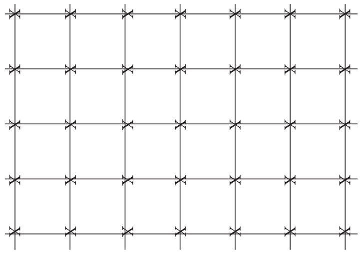
- A folded sheet of textile is sandwiched between two sheets of metal garden fence.
- The rig is prepared, and the contour of the curved wall is cut out of plywood for the top and bottom of the rig.
- Two layers, pp textile and the fencing net, are attached to the rig on one side.
- Reinforcement is prepared and placed in the formwork.
- The two nets are tied together with metal wire.
- The formwork is poured and compacted with an internal vibration stick and by external 'poking'/punching. The formwork 'survives' without blows.[4]

STEREOGENEITY OF THE NET WALL

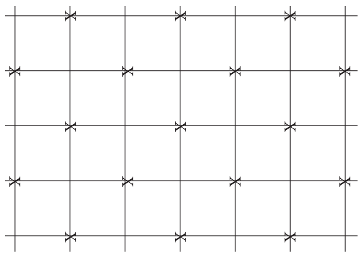
The structure appears as a slightly curved geometric shape; the surface has bulges of identical rectangular restrictions and tiny folds and creases on the inside of the curved wall.
The ends of the element are formed by the impacted wooden laths of the formwork frame.

At first glance, the bulging surface appears regular, but a closer look reveals that the geometries of the bulges do not quite follow the overall square imprinted pattern.
Up close to the element, one sees tiny bits of metal wire embedded in the concrete, and there is a correspondence between these wires and the tiny dents in the concrete surface – one realizes that the wires must have contained the shape from within.

The overall stereogeneity does not clearly express the full becoming of the wall. Eduard Sekler would use the term *atectonic*, because the grid pattern of the net appears to be pushed into the concrete surface from the outside – and not, as was in fact the case – pulled from within. On the other hand, even after a closer look the net definitely appears to be part of the structural formwork principle for the piece, and the extra layer of restraint, *the ties*, further articulates the concrete surface, and the structural ties are not completely hidden. The complexity of the surface pattern calls for further investigation, which in does reveal its *geneity*.



Tie pattern at the bottom of the formwork. Due to high formwork pressure every intersection was tied.



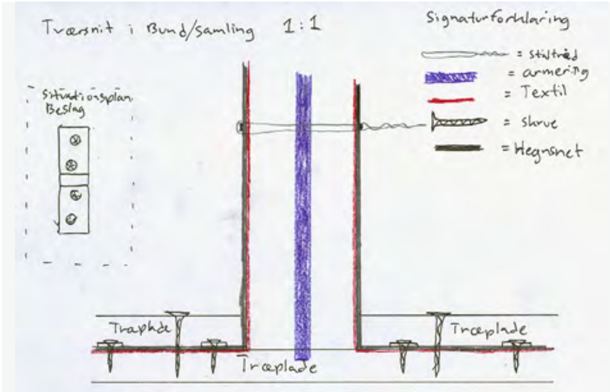
Tie pattern at top of formwork. Only every other connection is tied.

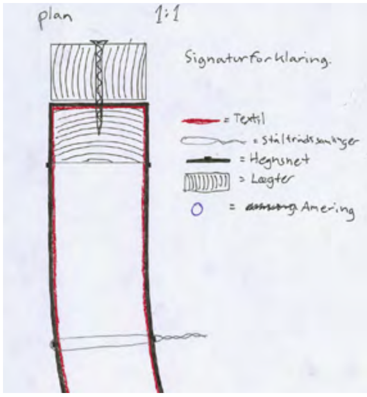
Roles of the forming and the restraining agents in Net Wall

Despite the clearly identifiable formwork principle, the structural form tie and the rhetorical forming principle in *Net Wall* are not identical; as stated in the reading of the stereogeneity above, the rhetorical and structural meaning of the two principles do, however, overlap.

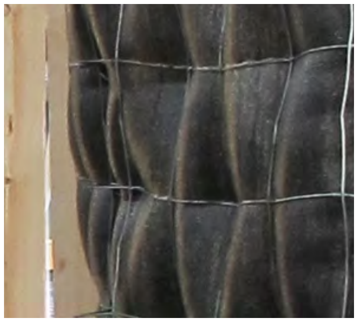
The analysis of the overlaps of the forming and restraining principles in *Net Wall* will draw on the student report about the workshop with the purpose of investigating how the students translate the clear experimental-physical 'terminology' developed during the workshop into

Left: Sketch from report: plan of the wall placed as a curved diagonal on a euro pallet (80x120 cm). This is a simple and uniform geometry as opposed to the initial free-form sculptural form.
Right: Sections showing formwork details.



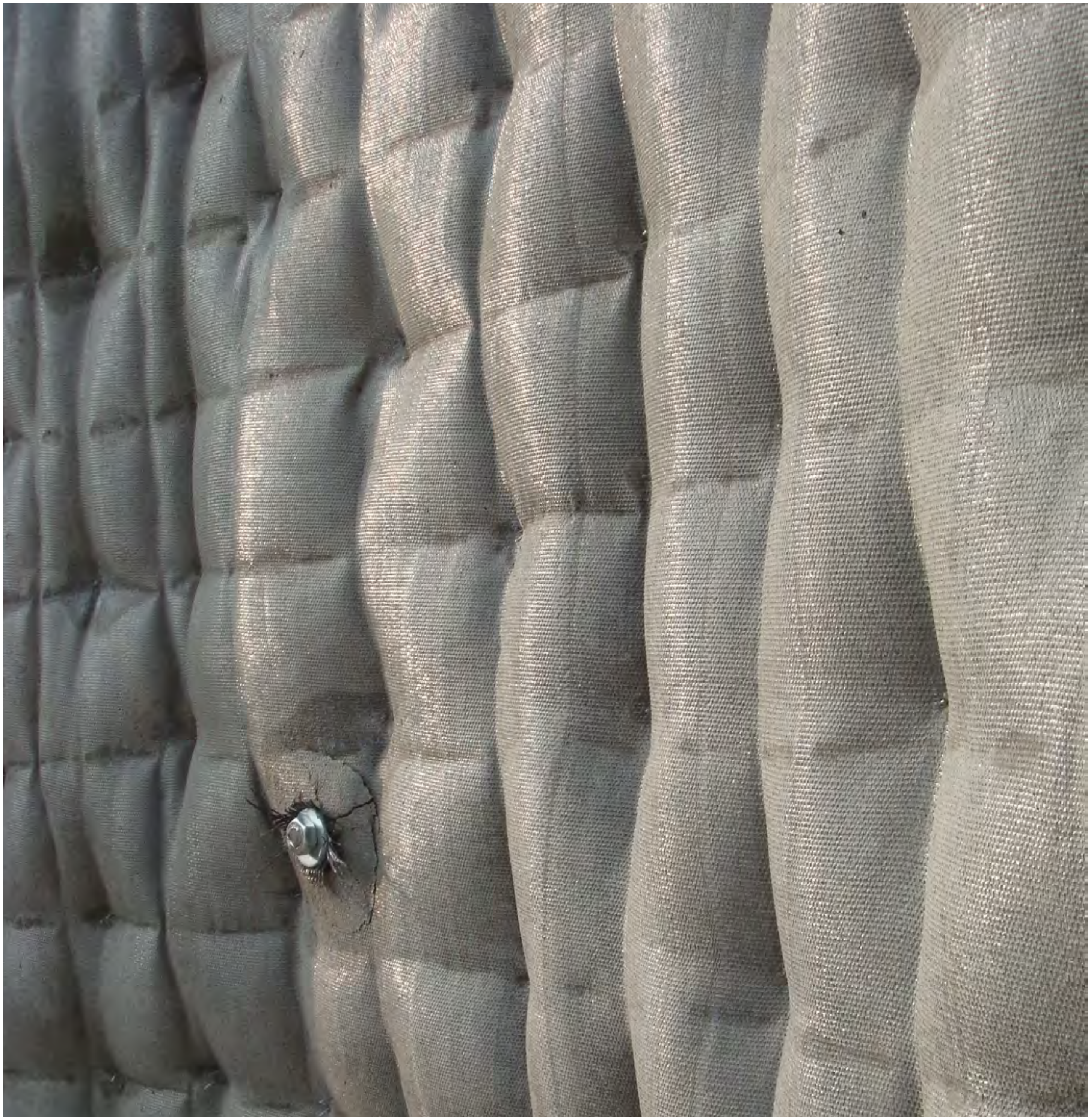


Plan, detail that shows textile and net folded around vertical frame element and braced



The newly filled formwork structure. The alternations of ties result in variations of bulges clearly visible on the surface.

Forming net and formwork fabric removed from the Net Wall. The pattern from the net shows on the fabric between 'cement-water' filtered through the surface.



Detail of the concrete surface. The grid line of the fencing net is clearly visible as are the variations in bulges as a result of the form tying principle writing. The students describe their working process in writing through descriptions of their formal ideas and the development of the formwork principle throughout the workshop, concluding with a few images of the resulting concrete structure. Sometimes these semantic descriptions change, within the same sentence, between referring to the formwork structure and referring to the resulting concrete wall. As described in their report, the students aim at making a formwork structure that has an "*air of something organic*". In the same sentence, it is the concrete wall that is described as organic.[5]

Despite the slight confusion in describing what it is that should to be organic, the procedure for achieving it is described quite clearly. The major formwork element is the net. The net is lined with fabric, which will bulge through the net pattern under the hydrostatic pressure of concrete.

In describing the net, the students use the term grid. This word has a wide range of uses, especially in architectural terminology where it can mean a conceptual as well as a physical, rigid structure. The physical structure may be the street layout in a city or a rigid lattice on a much smaller scale. What meaning do the students attach to the grid? Does the term refer to the orthogonal rigidity as opposed to the bulges in the fabric through the fence?

Are the students just confused about the semiotic meaning of the terms, or does their choice of words in fact reflect a structural change in the properties of the net throughout the construction process?

Net Wall: Student clip off all the remaining ties embedded in the concrete surface

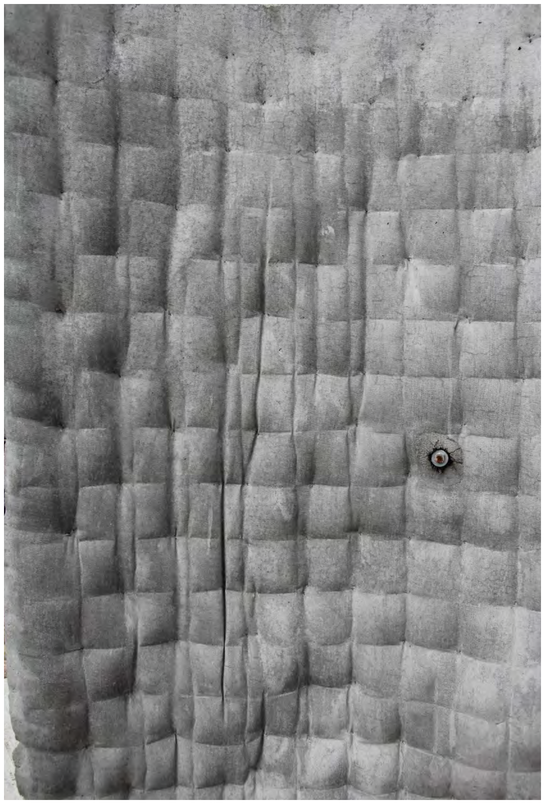
Scale model in plaster

The group constructed a small-scale plaster model to test their formwork principle. Chicken wire is used to construct light cage structures for animals and as reinforcement for plastering. The mesh has a hexagonal structure inspired by bees' honey combs, yet, the students do *not* seem to associate this ordered structure with anything organic. That may be why they refer to the net as a grid. Are they perhaps implying that the grid is something that is structured by humans?

In a formal sense, the students associate the organic quality with the flexible textile, which contains properties to be formed in all sorts of ways,[6] and thus *organic* appears to be similarly difficult to specify as something that can be shaped in all sorts of ways;

At the same time, the term *organic* might be a semantic statement such as concrete cast in a nonlinear mold. The organic is then associated with the bulges, which seem difficult to describe and control – they have a 'mind' of their own, and it is the forming by hydrostatic pressure that generates the organic form.

For the initial 1:5 scale model poured in plaster the idea was to free-form the chicken wire and let this structure resist the pressure of concrete held in the fabric form liner. The group tested this in a plaster mold and realized that the formwork pressure was too big for the net to act as the form-giver. In the plaster model the chicken wire is given two roles with regard to the effect in structure and surface of the plaster. The chicken wire is the overall forming, structural element, the *grid* that is used to *suspend the fabric-lined form*work.[7] The other role of the chicken wire is to impart the pattern geometry, as it will show directly on the cast surface.



A significant development process took place from the group's initial design idea to the final formwork structure. The students had some chicken wire in their studio. This was used to mold the small-scale plaster model. Chicken wire is a hexagonal mesh made from galvanized

Plastermodel cast in formwork embraced by chicken wire mesh. The mesh was unable to maintain its shape under the hydrostatic pressure of plaster

steel wire of less than 1 mm in diameter. The thinness makes the mesh pliable, and the metal retains the molded shape. As opposed to an orthogonal mesh, chicken wire has essentially no primal directions; this gave the group full freedom to play with the structure as form. However, the pliability applies to hydrostatic pressure as well. The free form play did not go well when the mesh had to perform as formwork, and it came to pouring liquid plaster into the form. The chicken wire mesh was intended to be a form-embracing device, but wet plaster proved to apply much more pressure than the chicken wire could withstand to maintain its shape. Instead of a tall, slender, free-form figure, the plaster object became rounded and fat. The chicken wire mesh showed its textile nature and deflected into catenaries under the hydrostatic pressure of the poured plaster. The structural and formal failure made this scale model a successful learning experience. The group realized that the surface would be bulgy as anticipated, but that hydrostatic pressure would deform the formwork net unless it was aided with either clamps or some other form of support.

Roles of the form tie in Net Wall

After the lesson from producing the plaster model the group reassessed their dogma of not perforating the formwork in the full-scale formwork structure; they did, however, maintain an ambition of letting the concrete surface be defined only by the pattern of the forming mesh and the bulges of fabric.

The net proved a strong forming concept for the form and surface of the concrete structure, so the group discussed two ways of keeping the concrete surface free from clamp holes: external support and internal binding.

An initial idea of restraining the formwork net from the outside with numerous 'invisible' *support fingers* was abandoned, because it seemed unsure how this device should be made and controlled, whether it would in fact be invisible or even be able to function at all, after what the group anticipated would be a laborious process.

Instead the group reversed the concept of many small external supports to a concept of connecting the fences from within the formwork; in this way they would be able to control the form and the thickness of the wall by designating the length and placement of ties.

Technically the group had now introduced clamps, but as they reduced the dimensions, multiplied the numbers, and left the ties in the concrete they were eventually able to avoid the clamp holes that they found to be a disturbing feature on the concrete surface.

The fence nets were tied together with steel wire. At the bottom, the formwork was tied together at each intersection, in this case every 10 cm. Halfway up the formwork, the formwork pressure will also be half what it is at the bottom so only every second connection was tied, thus every 20 cm.

The intention was to clip off the wire from the concrete surface when the fabric was stripped. By introducing a technical principle of tying the form, the group had also prepared for subtle variations in the concrete surface. Rhetorically, the garden fence dictated the overall form as well as the surface character of the concrete structure. The overall forming principle in which traces of the embracing garden fence appeared on the concrete surface fence would also become the major structural feature of the formwork. The 10 x 10 geometry of the fencing net became an important factor for the form-tying principle.

As mentioned, the students had difficulties distinguishing in their descriptions between their formwork principle and the desired concrete expression; the descriptions overlap. Apart from confusing the end and the means, this indicates the direct stereogeneous consequence of their decisions and hence the changing role of the matter they were discussing. In this regard, it is interesting to follow this process of identifying the notion of the net compared to the grid.

The students use the word 'grid' with a variety of meanings and on several scales, both as a conceptual system and pattern and as a somewhat unarticulated description of a physical grate or latticework. In the latter case, grid appeared to mean several of these things. It seems that in the students' mind, the close study of the major formwork element in their formwork principle develops into a form-giving agent. In this case, the imprint of the net in the concrete surface becomes a grid; the instrumental physical formwork element is transferred into an understanding of a complex concrete surface that contains the relationship between the unordered *organic* structure (the bulges) and the orderly, measurable and controlled structure (the square grid-pattern). One other group in the TEK1 workshop series used the *Net Wall* as a reference. They used the same wording, describing the use of a net as a grid - no other groups used this term or the technique.[8] We can dig deeper into the technical-physical meaning of the two terms, grid and net. At one end of the scale we find the grid defined as *lattice*[9] or *grate* on a material level, which may be strong, rigid and sturdy. At the other end of the scale is the *metal netting*. Gottfried Semper defines the net as a series of connected weavers' knots; hence it has a textile character: large tensile strength, individually tied knots, and an embedded flexibility between the knots.

Choosing the word net to describe an embracing restraint system implies an apparent compromise between rigidity and flexibility; on one hand, the strength and rigidity of a grate makes it possible to maintain a structural form, and, on the other hand, the flexibility of the net enables the formal freedom associated with its textile nature.

An explanation of the apparent confusion in the student report, between the notions of the flexible net and the rigid grid (grate) is a transformation of the properties of the former to become the latter during the form-making and construction procedures; by simply tying two sheets of flexible fencing net at numerous points the students create a rigid sandwich structure.

In conclusion to this reading we can define the embracing net as a 'stiff textile' when it acts as the conceptual form-giver and as a 'soft lattice' when it acts as the major structural formwork element.

Such an elaboration of the understanding of the *textile* adds to the level of textile thinking and doing in fabric formwork.

1 The student group named the project 'Wall de Mort'. Creative and amusing, the pun on a fictional caracter is not descriptive, so for clarity's sake the wall has been renamed in the dissertation.

2 March 8-19, 2010, 45 second-semester architecture students from RDAFASA participated in the workshop as part of the mandatory course TEK1, 2010. Fifteen DTU Arch.Eng students from also took part in the workshop. The workshop was planned and taught in collaboration with fellow researchers architect, Industrial PhD student Johannes Rauff Greisen and engineer, Ass. Professor Finn Bach. initial sketching and plasterwork at RDAFASA, formwork building at the Technical University of Denmark (DTU), final pour at RDAFASA. See Appendix/5 for further details of the assignment and the experimental data.

3 Considering the one-week duration of the workshop, the brief to construct the wall element appeared too challenging to allow for structural relations with the formwork of other groups, mostly because the details of the formwork structures were developed during their construction.

4 Most of the walls constructed during this workshop did not hold during the pour due to insufficient detailing between textile and frame in the formwork structure.

5 From the report in Danish: "*have noget organisk over sig.*"

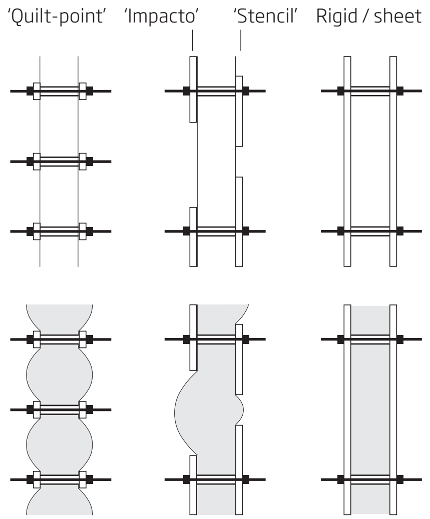
6 Ibid: "*[V]ores forskalling til en vis grad skulle have noget organisk over sig, fordi vi gerne ville udnytte at tekstilen er fleksibel og kan udformes på alle mulige tænklige måder.*"

7 "*udspænde en form*"

8 "We agreed that a grid might be an option. The grid should be in the form of a large metal net to be placed on top of the textile, so that the textile would bulge up through the openings of the grid," translated by the author "*Vi blev enige om, at et grid kunne være en mulighed. Griddet som skulle være i form af et stort jernnet, skulle lægges ovenpå tekstilet, og derved ville tekstilet bule op mellem griddets huller.*" "8.8"(898 group report, TEK1 2010, on appendix DVD, 6).

9 Semper, *Style*, 624. Semper describes the lattice as a 'complicated frame' between the categories frame and the supports in the 'task of the tectonic'. It is complicated because it combines a tectonic material and a textile technique within Semper's four-element scheme that is illustrated in the *Introduction and Research Questions*

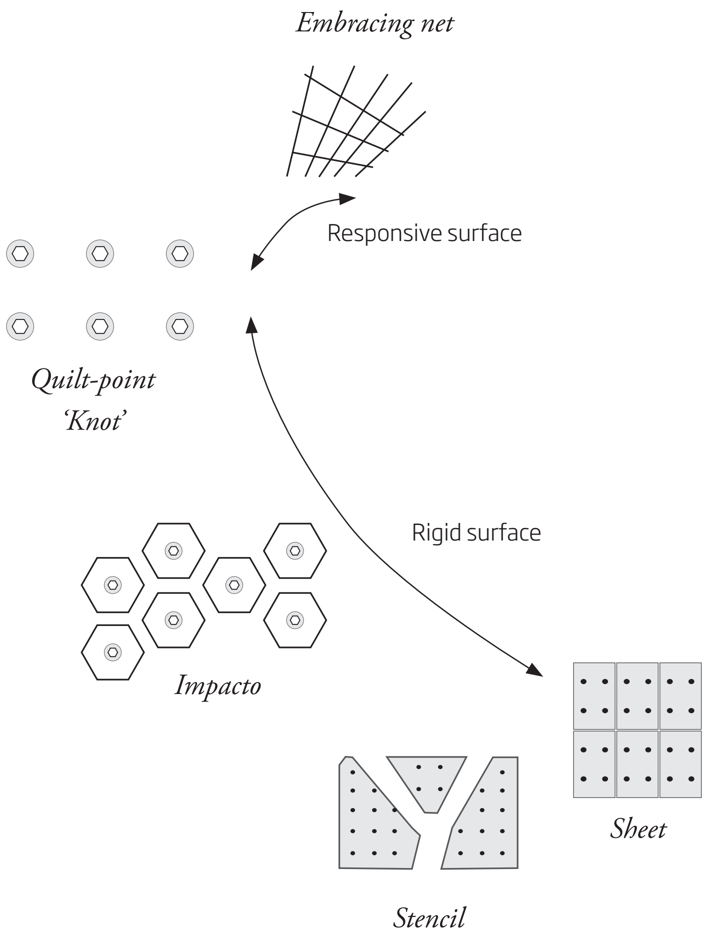
POTENTIALS FOR THE FORM TIE



POTENTIALS FOR THE FORM TIE

The *form tie* describes a group of formwork elements with a restraining role. The technological roles of the form tie have been the subject of the analytical studies of the *Clamp Wall* and the *Net Wall.*

The technical role of the *form tie*, as individual clamps or more widely connected tying systems, is to tie and restrain the two sides of formwork from deflecting under the hydrostatic pressure. The direct stereogeneous consequence of the design and placement of form ties in fabric formwork adds a strong rhetorical significance to a technical necessity.



Ornamental potential of the form tie

The ornamental potential of conventional form ties for rigid, planar formwork is a matter of geometric pattern of tie-holes as well as the subsequent articulation of these tie-holes, which Tadao Ando became an exponent of, with projects such as the Kujo Residence. For responsive formworks these aspects are supplemented with the expressed material dialogue of a responsive membrane, the articulation of the tie under formwork pressure. The formal potential of the square *impacto* used for *Clamp Wall* and to a more elaborate degree in *Chalmers Column* represents a direct ornamental application.

The large *S-Wall*[1] illustrates the *form ties* as *block-outs,* and the rugged detailing illustrates the potential for the form tie as a block-out to articulate the surfaces facing the concrete. This detail is relevant for all formwork systems but deserves particular attention in responsive formworks, as this block-out highlights the difference between the properties of the formwork textile and those of the material used for the block-out. In this regard, the use of the *form tie* as block-out illustrates the immediate exploration of the overlap between the low-tech behavior of fabric formwork and high-precision CNC[2] fabrication.

Stereogeneous thinking with the form tie

An ambition of developing the notion of *formwork tectonics* in direct relation to *stereogeneity* involves considering procedures and structural elements of the construction process for concrete as part of a strategic design methodology, a stereogeneous way of thinking.
The *form tie* links literal and symbolic 'tying form', and as an easily understandable notion it can become a distinctive strategic design tool of in the kit of formwork tectonic parts.

The notion of a stereogeneous mindset describes a practice of carefully construing a concrete structure and architectural space by considering its becoming, it's the principles of formwork tectonics.

Towards the origins of concreting

A stereogeneous thinking is a radical approach because it 'goes to the roots' of pouring concrete. Radical as an adjective can be defined as "of or relating to the root, source or origin."[3] Used in this way, the word 'radical' also describes fabric formwork. For fabric formwork the technical and rhetorical meaning of tying form simply overlaps to an extent that unites the Semperian knot as the oldest technical symbol with Frascari's focus on the joint as the generator of architectural meaning.[4]

This suggestion is far from subtle, but neither is the mediating role of the form tie in the

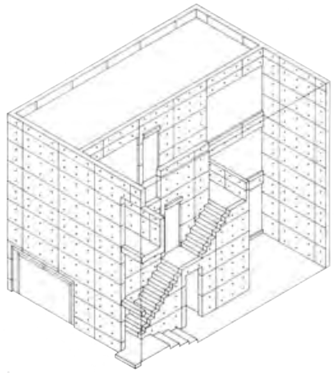
contrasting material dialogue between poured concrete and textile form.
It should be clear here that the role of the form tie is different from the textile and the concrete, which both have properties that remain the same within the material group that they belong to.[5]
One is reminded of Richard Sennett's book about the *Craftsman* and the three incentives of the craftsman for entering into change: metamorphosis, presence, and anthropomorphosis.[6] Going toward the roots, toward an origin of casting as a craft, points to the fluid origins of concrete and to the craftsman's fascination with its metamorphosis. However, the form tie in stereogeneous thinking is based on the significance of the knot as a technical symbol and points directly to the notion of *form-making* by the hand of the maker, not necessarily to an *expression* of the fluid origins of concrete. Richard Sennett's understanding of *presence*, the mark of the maker, originates from an actual stamp used in brick-making, "*fecit*": "I made this," "I am present in this work."[7] Using the form tie as *impacto* and block-out points to a particular articulation of the joint on a technical as well as a rhetorical level. In the context of this thesis, the concept of the maker includes the designer and the builder. When the form tie takes on important technological roles, its articulated design and careful detailing require accuracy and attention from the builder. At the same time, these points and their stereogeneous consequence may enhance the enjoyment of construction for the builders compared with the more neutral formal consequences of the builders' work.

The many nuances of the design and functionalities of the form tie and its direct stereogeneous consequence as a formwork element make it an architectural notion in a wider sense. The form tie is highly articulated and adorned in fabric formwork, but its dual-sided technological role allows it to be considered for other formwork principles as well, and thus a general stereogeneous thinking for developing the form and structure of a wall cast in situ could begin by working through the notion of the *form tie,* exactly *because* the form tie is a fundamental formwork element for in situ construction.

The diagram to the left is a way of displaying three degrees of restraint and form-tying principles. One can conceive the form tie as originating from the knot and depicted as the *quilt-point.* The difference between the understanding of the *impacto* and the *stencil frame* is that the *impacto* represents an addition of a 'rigid surface' to the point, while the *stencil frame* represents a removal of surface from the rigid sheet. The *embracing net* is seen as a Semperian system of knots (points); this system is further rigidized when represented as the *lattice/frame*.

The construing of structural formwork principles starts from the *quilt-point* of the *form tie* and enters a virtual material dialogue among types of restraining formwork elements and concrete. When our virtual material dialogue is initiated with the articulated knot, we can continue and claim that if the notion of textile as a responsive sheet is inserted into the discourse, it will act as an obstruction[8] that is handled either by adding surface to the knot – which makes an *impacto* – or by defining the connected system of knots to a responsive net in various ways.

The depth of the form tie is not depicted in the two diagrams to the left, as it varies between the thickness of a specific *impacto* to the articulated solidity of a block-out. (See the detail of the *Chalmers Column*, right)



Axonometric drawing of Kujo House (Japan) Tadao Ando, 1982. This stereogeneous drawing can be compared with the construction drawing for Salk Institute in the chapter Concrete and Concreting.

Impacto and block-out, Chalmers Column, (appendix 5.1)

1 TEK 1, 2010, appendix workshop 5

2 Computer Numerical Control

3 Radical in *The Cassell Compact Dictionary* (London: Cassell, 1998).

4 Frascari, "Tell-The-Tale," 498-514.

5 The technique and fibers used to produce a textile may vary, but the textile still deflects in catenary curves when force is applied. Similarly, numerous concrete mixes still result in a fluid mass with a hydrostatic pressure.

6 Richard Sennett, *The Craftsman* (Penguin, 2009), 120.

7 Ibid., 130. As retold by Sennett.

8 Jørgen Leth and Lars von Trier, *The Five Obstructions*, Documentary, 2003. Obstructions as a creative generator are familiar to all creative professions. The Danish documentary is an example from filmmaking. and describes the creative play of challenges set between Leth and von Trier.

ANALYTICAL STUDIES OF THE TEXTILE

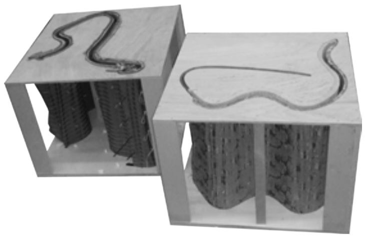
INTRODUCTION TO THE TEXTILE

STUDY OF THE AMBIGUOUS CHAIR

STUDY OF THE COMPOSITE COLUMN

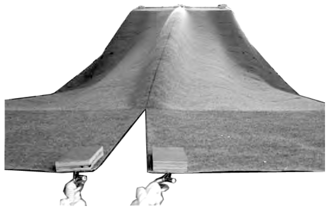
STUDY OF THE FABRIC-FORMED RIGID MOLD

POTENTIALS OF THE TEXTILE



Ambiguous Chair

Composite Column



Fabric-Formed Rigid Mold

TYPOLOGY	TITLE	PARTICULAR FORMWORK ELEMENT	CONTEXT
COLUMN	Sinus Column	FRAME	CAST, Exhibition 2007
COLUMN	Composite Column	TEXTILE	PhD, TEK1, 2010
BEAM	Form-Efficient Beam	FRAME	PhD, ESALA 2007-10
WALL	Clamp Wall	FORM TIE	TEK1, 2009
WALL	Net Wall	FORM TIE	TEK1, 2010
SHELL	Fabric-Formed Rigid Mold	TEXTILE	CAST 2009
SCULPTURE	Ambiguous Chair	TEXTILE	PhD, Exhibition 2009

INTRODUCTION TO STUDIES OF THE TEXTILE

While the form tie and the frame are formwork elements shared with conventional construction systems, such as system formwork, the textile element is the new tool in the box of formwork tectonics.

Textiles used in the experimental work that will be analyzed in the following three studies hold a number of different structural roles that can be explained through descriptive analysis; the formwork can be described as hung,[1] or the tensile strength of the textile can be used structurally as form *finders* and form givers[2] for concrete cast in hydrostatic formwork,[3] a role that is included in the term *embracing* as defined in the initial categorizations of experimental data. The fabric used in formwork can also act technically as a container, a bag for concrete that is given form and held up by something else; this has been referred to as embraced textile.

These descriptions may be useful in describing the technical aspects of construction, and they correspond with the general objectives ascribed to textiles by Gottfried Semper: to *cover,* to *protect,* and to *enclose*.[4]

In the attempt at unfolding the architectural potentials of the formwork tectonics of fabric formwork, analytical studies will include technical and rhetorical roles. As presented in the introduction to the dissertation, textiles are understood here as structure as well as surface.

The newness and, more importantly, the complexity of the notions and principles of textiles used as a responsive surface material in formwork structures makes this section of analytical studies the largest of the three sets of analytical studies.

The following studies feature textile used as structurally embracing surfaces (in the *Ambiguous Chair* and the *Composite Column*), textile surfaces manipulated to *become* structure, and textile structures as a form-giving element (in the *Fabric-formed Rigid Mold*). The differences between these textile categories may seem subtle, but they do, however, qualify a key argument in this thesis that the naming of potentials for fabrics in the construing and construction of concrete structures requires an understanding of textiles as both surface, structure, and metaphor.[5]

In the attempt at unfolding the architectural potentials of the formwork tectonics of fabric formwork, analytical studies will locate and interpret instrumental and rhetorical roles.

Ways

In the architectural scope of this dissertation, the descriptive *how* and *what* of textile construction is supplemented with the interpretive *why* and a *so? What* refers to the properties and behavior of the specific textiles represented in the experimental data. *Why* refers to rhetorical aspects: intensions as well as the *stereogeneous* consequence of the structural use of textiles.

Questions

In regard to the dual-sided technological role of textiles in fabric formwork, the questions investigated in the following studies have to do with textile notions and principles in the formwork and how these are transferred to the concrete structures, how they are expressed as concrete sculptural form, and what consequence they have for concreting and construction.

The latter issue frames a second group of questions concerning how the development of an architectural vocabulary that stems from this 'textilization' in formwork tectonics alters the understanding of architectural concrete.

1 In which the fabric self-stresses. The *Chalmers Column* is also hung from a tripod frame structure.

2 Chandler, Alan and Pedreschi, *Fabric Formwork*, 7. Chandler describes form-giving as the methods of construction to build forms that are 'found' via the self-organization of membranes on small scales. In the present use, the term form-giving means to *give form*, that is to say the forms are not intended as form-optimized in a technical sense.

3 Ibid.

4 Semper, *Style*, 113.

5 As established in the Conceptual Framework chapter

STUDY OF THE AMBIGUOUS CHAIR

Author: Anne-Mette Manelius, assistant Jannie Bakkær Sørensen

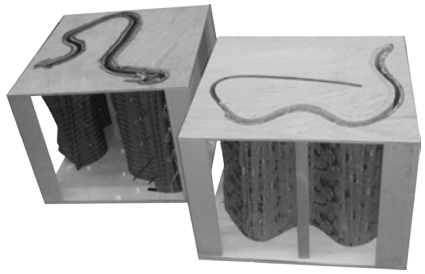
Year: 2009

Context: Exhibition, Scandbuild Building Materials Fair

Part of CINARK's exhibition stand at Scanbuild 2009

STUDY OF THE AMBIGUOUS CHAIR

Structural typology of concrete	Sculptural object (chair)
Structural typology of formwork	Rig with prestressed fabric
Role of fabric in formwork	Embraced
Type of restraint in formwork:	Clamps
Reinforcement	∂-chair reinforced with PVA[1] fibers S-chair reinforced with 6-mm rebar and PVA fibers
Concrete type	ECC[2] with polymer additive, PVA-fiber reinforced
Concreting procedure	Pour on vibrating table
Short description of formwork principle	The sculptural object shaped to form a lounge chair, cast in furniture fabric and restrained with point-clamps to create a continuous upholstered look and 'textile' surface. Chair has holes to drain off water.



This analytical study focuses on the rhetorical and instrumental roles of textile in two sculptural objects, entitled the *Ambiguous Chair*, made for an exhibition.[3]

The formwork principle was based on Kenzo Unno's quilt-point *method*, and findings from student workshops at the University of Edinburgh.[4] The experiment would make this theoretical and 'passive' knowledge of fabric forming into 'active' knowledge through the engagement with practical methods and the response of observers.

The *Ambiguous Chair* was the first experimental series created by the author, and of all the analytical cases it contains the most complex program, as introduced in the following.

The context of the exhibit was co-exhibitors from CINARK at the trade fair.[5] A concrete chair and table from the series *Concrete Things* were to be exhibited[6] at the exhibition stand. These objects were designed as solid blocks; the seat for the chair was a hollow 'carved' out of the block. *Concrete Things* weighs 500 kg.[7]

The author chose to display a contrasting object and decided to make fabric-formed concrete objects matching the *Concrete Things* chair in function. Another aim was to display characteristics of the fabric formwork technology by constructing complex geometric forms and aesthetic concrete surfaces that could only be cast in fabrics. The final aim was to create a surprise encounter with concrete by enhancing textile notions.

1 Poly Vinyl Alcohol

2 Engineered Cementitious Composite. This mix contained no large aggregates.

3 Scandbuild tradefair, March 30-April 2, 2009 at Bella Center, Copenhagen. Centre of Industrialized Architecture (CINARK) was invited to arrange and produce a special exhibition of current research projects near a stage in the 'event space' of the fair and near the entrance.

4 Remo Pedreschi in lecture at "ICFF2008". Students had cast in fabrics bought at a 'hobby' store and experienced direct transfer of dyes, patterns, and surface textures.

5 The CINARK exhibit at Scandbuild 2009 showed material research and publications by Anne Beim, Johannes Rauff Greisen, Nini Leimand, Peter Andreas Sattrup, and Kasper Sanchez Vibæk.

6 *Concrete Things* was exhibited as an example of CAD CAM technology used for milling concrete formwork, the subject of a newly initiated Industrial PhD project by CINARK scholar, architect Johannes Rauff Greisen with the Technological Institute of Denmark as industrial partner.

7 www.teknologisk.dk/specialister/25948?cms.query=stol (accessed 14-02-2012).

Collumn cast by CAST at Creative Systems 2007 (appendix, workshop 1)

Concrete object with print transfers from the formwork fabrics, the 'cemetary' of the University of Edinburgh where fabric-formed objects from previous workshops are stored.

Context, Observers and Function

The exhibition of the *Ambiguous Chair* was the second exhibition in Copenhagen where characteristics of the technology were on display. One of the *Three Columns* at KA,[8] 2007 had a highly artistic, sculptural and phallic look with a rope and iron spikes on top. Reactions and discussions initiated during the columns workshop[9] generally revolved around the strong artistic presence of the maker of the columns. The phallic column was simply very peculiar, and it seemed that the particular context of the display of the technology had not affected the design of the fabric formwork.[10] This resulted in specific considerations of the author to add *context* and *observers* as parameters to the experimental design.

Exhibition aim for the Ambiguous Chair

The *Ambiguous Chair* would primarily attract observers at the trade fair.[11]

In regard to context and observer the architectural aim of the experiment to elaborate on associations with fabric formwork that can be described as an oxymoron, a term that contains two terms of opposite meaning: fabric and formwork. The architectural exploration of the oxymoron was suggested as a possible strategy for creating a new perception of concrete and initiating a dialogue about the potentials of concrete architecture cast in flexible fabric forms.[12]

In this regard the point of departure for this experiment was a play on notions of textiles as something light and delicate, which can be draped and tailored. According to Semper, the general purpose of textiles is to cover, to protect, and to enclose.[13] This broad definition covers a multitude of functions: covering the body, the floor, furniture, a spatial enclosure etc. The understanding of (rigid) formwork also includes a function of enclosing, albeit only temporarily, as it contains wet and heavy concrete until cured.

The specific experiment involved the design and production of two fabric-formed chairs and the presentation of these physical objects, which had a familiar function and scale but which simultaneously contained ambiguities of the expressed and sensed aspects of materiality, methods of construction, function, and 'softness'.[14]

Architectural aims and theoretical description

Major influences in the *Ambiguous Chair* experiment included the quilt-point method[15] and experiences from studio workshops at the University of Edinburgh, where textiles bought at a local store selling textiles for hobby crafters were used as concrete formwork; this produced surprising effects as patterns and colored prints on the textiles were transferred to the concrete surface.[16] The American architectural theorist Marco Frascari would define this theoretical knowledge as 'passive', because it is based on images and descriptions as opposed to the *active* understanding of physical experiences of making and/or actual dialogues about construction processes.[17]

The *Ambiguous Chair* experiment is a physical summary of previous literature studies; it is an occasion to transform 'passive' understanding of construction with fabric formwork to 'active' knowledge.

The third influence on the experiment can be described in the psychological terms of affordance theories[18] and Gadamer's philosophical concept of 'horizons' to explain this quite

8 Appendix, workshop 1.

9 The small workshop had many visitors, as it was carried out outside the main auditorium building at KA in the busy beginning of the school year and at the time of a conference and exhibition called Creative Systems; Anne-Mette Manelius and Anne Beim, "Creative Systems – Arkitektur i en nyindustriel kontekst" 2007, no. 14, Arkitekten (n.d.): 48-52.

10 Reasons for the lack of sensibility to the context may include the fact that the workshop was arranged only a few weeks prior to the conference and exhibition of *Creative Systems*, and that the design and preparations for the column formwork were made in Canada.

11 Later exhibitions of the *Ambiguous Chair* were held at the architectural office of the industrial partner and at the RDAFA on the landing outside the Institute of Technology and, for the S-shaped chair, outside in the courtyard on the RDAFASA campus since June 2010 [January 26 2012].

12 Anne-Mette Manelius, "AMBIGUOUS CHAIRS CAST IN FABRIC FORMED CONCRETE" (presented at the STRUCTURAL MEMBRANES 2009, International Conference on Textile Composites and Inflatable Structures, Stuttgart, Germany: CIMNE, Barcelona, 2009, 2009), 4. The author presented this aspect at the conference.

literal 'foregrounding of prejudice'[19] against concrete. In order to confuse the observers and spark a discussion about the potentials of fabric formwork, the general 'affordance' of this sitting object, must simultaneously achieve the look of material notions of upholstery. This look from a traditional technique for upholstering furniture is also the look of concrete cast using the quilt-point method. The specific selection of upholstery textiles aimed at enhancing the upholstered appearance of the concrete structure.

Structural formwork principle and design

The structural formwork principle for the *Ambiguous Chair* exploits the flexible nature of textile restrained by means of the quilt-point method and vertically pre-tensioned in a rig. The chairs are principally constructed as small walls, understood as extrusions of side elevations, cast on the side and subsequently turned upright.

A free-formed slit is cut in the top and bottom rigid plywood sheet of a rig; the slit is formed with both large and tight curves, and the design for the two chairs displays two different ways of creating a cantilevered seat. Textiles are mounted and tensioned along the edge and restrained with quilt points.

Selection of textiles and restraining method

The formwork textiles for the Ambiguous Chair were not designed for concrete casting. A selection of furniture textiles were chosen at a local hobby fabric store.[20] Yet, the textiles selected for the experiment had to comply with two requirements:[21] First, the pore size in the weave of the textile had to provide good transportation of water and air from the concrete surface during the pour; and second, the pattern of the textile had to transfer clearly onto the concrete surface as an aesthetic feature in accordance with the attempted upholstered look.

The main criteria for selecting textiles among the many types of fabrics at the store were low elasticity and high tensile strength;[22] next followed criteria such as contrasts in weaving structure and contrasts in material properties and production techniques with regard to graphic patterns and materiality (pattern added to the textile as post-treatment).

The selection of furniture fabrics included textiles that met the former criteria; the two latter criteria were used to select a range of textiles. Four textiles were selected, because the four samples represented a range of textile properties and tactilities that can be described and discussed as follows:

Textile Sample A

Textile sample A is a woven polyester textile with a smooth surface. It features no difference in the weave that is perceptible by the fingertips: The leaf pattern is obtained by weaving with two shades of gold-colored thread; the sample is the thinnest and most translucent textile with the highest elongation of the four.

Textile Sample B

Textile sample B is a tightly woven cotton-polyester mix; the textile has a striped pattern

13 Semper, *Style*, 113.

14 James J. Gibson, "The Theory of Affordances," in *Perceiving, Acting and Knowing*, ed. R. Shaw and J. Bransford (Hillsdale, NJ, USA: Erlbaum, 1977). The expressed softness combined with its function can be defined as the object's affordance

15 Developed as part of Kenzo Unno's URC system introduced earlier in the dissertation among construction principles for fabric formwork.

16 Lecture by Remo Pedreschi Remo Pedreschi, "Fabric Formwork for Concrete - Experiments in process, form and texture," in *Fabric Formwork Conference Speakers* (presented at the First International Conference on Fabric Formwork, Winnipeg, Manitoba, Canada: CAST, University of Manitoba, 2008), http://www.arch.umanitoba.ca/cast/7.remopedreschi/. AMM visited the University of Edinburgh during a student workshop October 2008 and cast a few surface samples.

17 The first act of what was introduced through Marco Frascari in the methodology chapter.

18 Gibson, J.J (1977) "The theory of affordances" IN R.Shaw & J. Bransford (eds.), *Perceiving, Acting and Knowing*. Hillsdale, NJ: Erlbaum

19 As introduced in the methodology chapter

20 Stof2000 at Frederiksborggade 26, 1360 Copenhagen

21 Examined via small cast test pieces.

22 Based on a subjective assessment of material properties by simply examining and pulling the fabrics in the store.

Test pillow A | Test pillow B | Test pillow C | Test pillow D

TEXTILE SAMPLE

IMPACTO MARK

FORM-TIE

CORNER DETAIL

TEST PILLOW

achieved by the weaving and consisting of fibers in various colors; it is possible to see and feel the different weaving styles that create the pattern.

Textile Sample C

Textile sample C is a sturdy woven cotton intended for bed linen; 1-mm thick cut-out, fuzzy patches of velour are attached to the fabric; the various textiles that make up the pattern can be detected visually and by touch.

Textile Sample D

Textile sample D is a velour textile with a metallic rubber print.

Construction of Test-Pillows

Test Pillows were made, using 30 x 80-cm samples of the four furniture textiles in order to test the applicability of the four selected textiles, to specify restraining methods and to test how slender one could construct the formwork while still managing to fill it during the concrete pour, and finally to test a concrete pour and the concrete result with an engineered concrete mix reinforced with metal fiber.[23]

Textiles B-C were considered very suitable in relation to the requirements. Because of its thin quality, textile A was not considered very suitable as formwork, but due to the surprisingly clear transfer of the pattern, the textile was included nevertheless. The pillow cast in textile D had the poorest surface quality and was not used for the *Ambiguous Chair*.

The metal fibers were visible at the top of the pour and considered unsuitable for the finished concrete object. Handling the objects would result in scratches from the sharp metal, which might also injure observers touching the chairs.

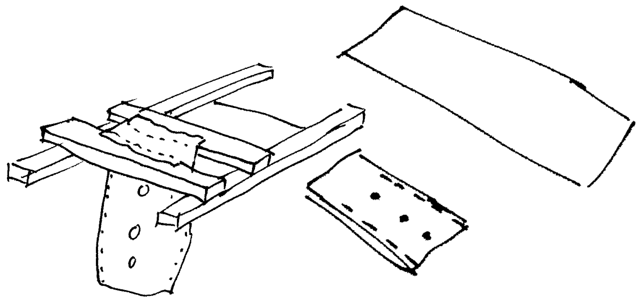
CONSTRUCTION OF THE AMBIGUOUS CHAIR

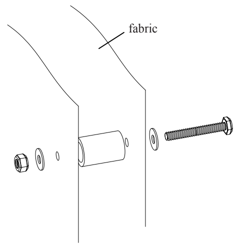
Two seating objects were designed to meet the criteria mentioned above; in the following, S and ∂ will be used to refer to each of the objects according to the approximated shape of their sections.

Textile B, a striped textile, was used as formwork for the S-shaped formwork structure; this design has the largest cantilever, so 6-mm iron bars were bent and tied in for additional reinforcement.

Textile A, which had a leaf pattern, and textile C, a textile with a velour pattern, were used for the ∂-shaped formwork structure. This design had a less pronounced cantilever, so the construction was tested without further iron reinforcement.

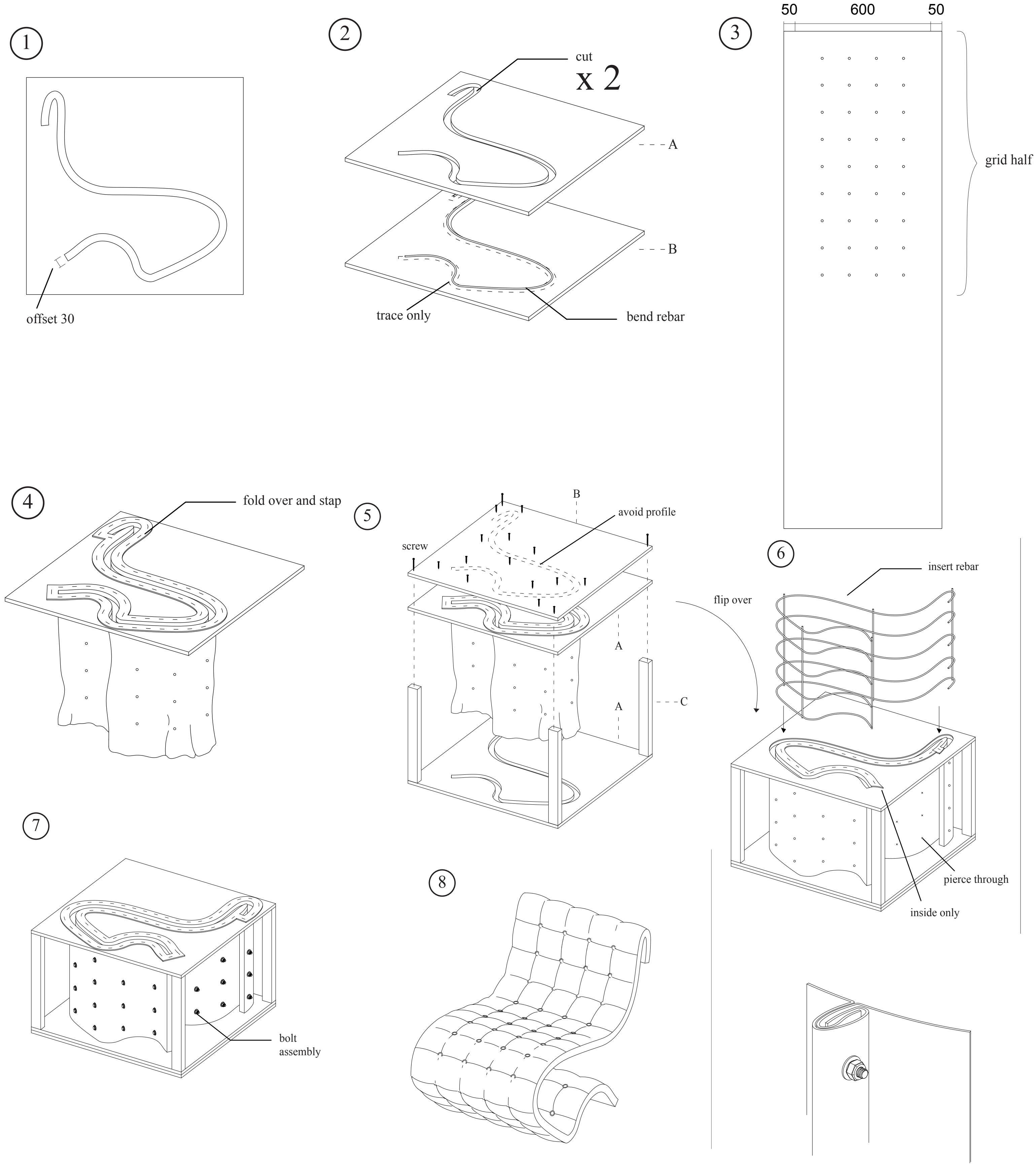
In short and corresponding with the illustrations on the next spread, half the length of the 200-cm lengths of fabric had pre-punched holes for the clamps in the selected 12 x 12-cm grid. The textile was tensioned to the 60 cm high rig with hundreds of staples and simultaneously clamped together with the selected restraining method with 16-mm washers. The pre-





The quilt-point principle for Pillow D was used for the chairs.

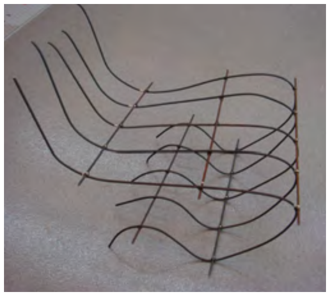
Adding the metal fibers. Below, images of the test pillow formwork



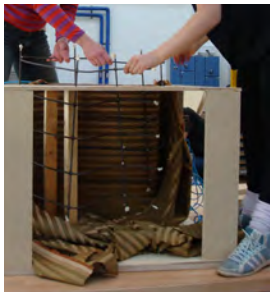
Closing/connection detail

Stapling fabric on the bot-
tom sheet

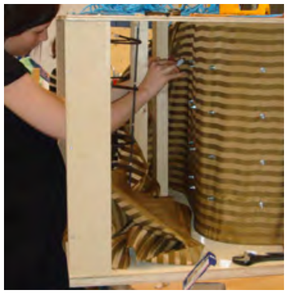
Fabric stapled on plywood



Reinforcement approximated and bent by hand.



Placement of reinforcement

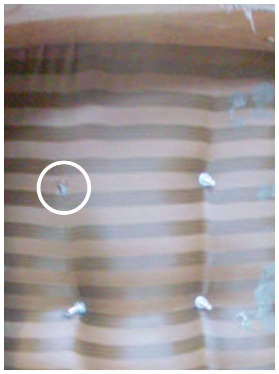


Montage of bolts and distance tubes around reinforcement.

PVA fibers - they fibers created lumps in the concrete mix

Concrete flowing out of the formwork between the two bottom sheets of the rig.

A repaired damage to the fabric during formwork construc-
ton broke again. It had been repaired to hastilly/poorly. Creases on the textile surface tell that the formwork has not been filled.

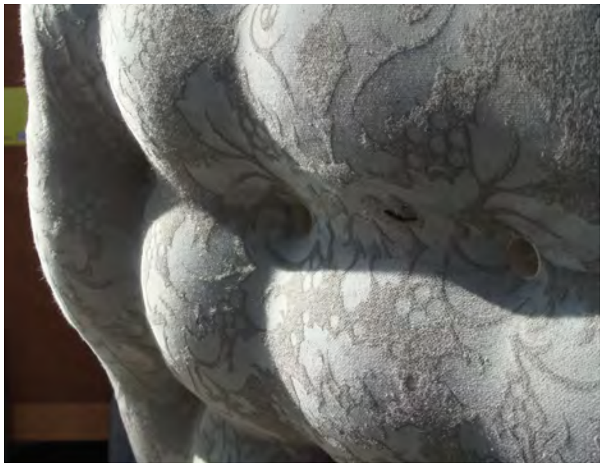


A form-tie disappeared through the textile; the tie was possibly too tight or the textile opening cut too large. Notice the small diameter of washers.

Several form-ties blew; bolts are embedded in the concrete Textiles A and C were used for this piece.

The form for S-chair was not filled completely at the termination of the pour.

Previous page, Step-by-step drawings for the *Ambiguous Chair*. Based on sketches by Mane-
lius, the illustrations are CAD drawn by Chris-
topher Stuart for the book Stuart, Christopher, ed. 2011. *DIY Furniture: A Step-by-Step Guide*. Laurence King Publishers, .



Top: Detail of concrete surface cast in textile B, polyester fabric with woven leaves pattern. Ambiguous Chair, (∂-chair)

Below: the velour pattern on textile C has transferred to the concrete surface; the formwork textile is darker where the pattern was glued, possibly because it was not in contact with the concrete mix or because traces of afhesive.

punched holes and the striped pattern[25] assisted in controlling the tensioning of the textile evenly in order to maintain the important geometry of the form-ties (clamps) and the surface pattern.

The pour of both chairs was carried out simultaneously on a vibrating table. The pour had to be terminated when one of the formwork structures leaked and deformed, and formwork ties blew.

STEREOGENEITY OF THE AMBIGUOUS CHAIR

Despite the identical formwork principles, the fact that several form-ties blew and the following termination of the pour resulted in very different expressions. The stereogeneity of both objects can still be described and is followed up by a discussion of the roles of the textiles.

The ∂-shaped Chair

The ∂-shaped chair has contradictory expressions of thin, flake-like concrete surfaces on one side, in fact the top of the pour, and heavy bulges on the other, corresponding to the bottom of the pour that had been subject to blown form-ties.

The sides of the thin flakes that had not faced the fabric form resemble gray cookie dough thus reflecting the special concrete polymer mix. The front and back surface of the chair has two different patterns, respectively from textile A and textile C. Textile A has left its leaf pattern on the smooth concrete surface; subtle changes in the direction of the weaving pattern are enhanced by the light falling on the surface. Textile C left a dramatic expression and a remarkably tactile look and soft feel. When textile C, the velour-patterned fabric formwork was stripped from the concrete, the formwork linen was left bare in many places, with no traces of the velour patches; this indicates that the adherence agent was dissolved either by moisture and/or the alkaline concrete environment.

See the appendix for further images of details.

The S-shaped chair

The S-shaped chair appears slender and with uniform thickness and an even distribution of form-ties. The object expresses the becoming of the piece: The bulging surfaces indicates the fluid origin of the poured concrete, and the formwork textile, textile B, has left an easily detectable pattern and even fibers on the concrete surface.

Reactions from observers

Reactions to the stereogeneity of the chair bring to mind that the tectonic expression for concrete is more complex than that of frame structures or stacked bricks, simply because a series of procedures in the concrete construction has led to a wide variety of outcomes with regard to the technical properties of the concrete and the form and surface structure of the formwork.[26] In order to dissect the processes of becoming in concrete structures, one must know of a number of material properties. This general observation applies to all analyses of

Top:Detail of concrete surface cast in textile C, cotton fabric with velour pattern. Ambiguous Chair, (∂-chair)

The sterogeneity of ∂-shaped chair: very heavy at the blown-out bottom of the pour (left side of image) and fibrous and paper thin at the top of the pour (right side)

Bottom, the S-shaped chair




Details of concrete object cast in textile B, polyester-cotton mix textile with woven striped pattern, Ambiguous Chair, (S-shaped chair) concrete structures – but it is especially relevant for the discussion of the expressed geneity of the fabric-formed chair because of the unconventional surface.

When the German psychologist Kurt Koffka[27] asserted that *"each thing says what it is,"*[28] he failed to mention that the thing may lie. *"More exactly, a thing may not look like what it is.*[29] This dilemma of 'affordance' also cover aspects of the retrospective reading of stereogeneity. If the observer is familiar with the idea of casting concrete in textiles, Koffka's statement may apply to the *Ambiguous Chair* – these objects may appear to the observer as concrete objects cast in upholstery textiles. If the observer is not familiar with the technique of fabric forming the tectonic expression is instead ambiguous, and Eduard Sekler would define it as 'atectonic'.[30]

When observers were confronted with the two chairs there was a shift between expectations derived from the optical appearance of the objects versus the actual tactile information obtained from engaging with the object – touching, sitting and maybe attempting to lift the object.

A few remarks from observers indicate that they find a sort of 'atectonics' expressed in the *Ambiguous Chair:*[31]

"Is the fabric still on the chair?" and *"This could not possibly be concrete."*

These remarks reflect how the concrete surfaces of the chairs have a defined fabric appearance in combination with a transfer of patterns and colored fibers. The observer who made the latter remark clearly doubted whether the soft-looking objects are in fact made of concrete.

Another observer was also confused:

"I looked at the chair, and in my rational mind I knew it was concrete and could not understand that it was not fabric. Then when I sat on it, in my rational mind I knew it was concrete and would be hard, but I was still surprised to find that the chair was not as soft as it looked."

The observers acted similarly: first, they took a look at the object. When they were told the author that it was concrete cast in a textile mold, they took another look, and then they touched the object. The object did not look as what is *was* to the observers, and they apparently felt a need to acquire what the Finnish architect and architectural thinker Juhani Pallasmaa calls tactile images[32] of the (hard) concrete object with the (soft) textile look, similar to children who touch and feel their environment in order to connect their visual impression with tactile input.

Several observers have associated fragility with the structure of the *S*-shaped chair and asked whether it will be strong enough, before they sit down. Whether this is due to the textile appearance, or whether it has more to do with the rather large cantilevered seat will not be discussed here.[33]

23 Chemical admixtures define some of the numerous designable properties of Engineered Cementous Composites. In this case, plasticizers add viscosity without changing the water-cement ratio.

24 See the appendix cd for a fuller description and documentation in Danish.

25 For the *S*-chair

26 Quotes were not recorded but written down by the author after conversations with observers, i.e. visitors at the exhibition.

27 (1886-1941)

28 Kurt Koffka (1935) *Principles of Gestalt Psychology*,Lund Humphries, London, Chapter 1, as quoted in James Jerome Gibson, *The Ecological Approach to Visual Perception* (Routledge, 1986), 138.

29 Ibid., 143.

30 Sekler, "Structure, Construction, Tectonics," 89-95.

31 The remarks included here made were by visitors to the construction tradeshow Scandbuild, held in Copenhagen in April 2009, in conversations with the author at the exhibit stand. They were mostly offered as exclamations, which led to conversations.

32 Juhani Pallasmaa, *The Thinking Hand* (Wiley, 2009), 27.

33 The S-shaped chair is still intact (November 2011) after several moves with cranes and being left outside for months in the snow and frosts of winter. Small surface cracks are now visible in the thinnest areas of the structure, and orange patches indicate rust from the reinforcing bars.

34 The field is immense. A recent Industrial PhD dissertation includes the development of games for user-participation, the subject of experiencing applied textiles via games. Anne-Louise Bang, "EMOTIONAL VALUE OF APPLIED TEXTILES - Dialogue-oriented and participatory approaches to textile design" (PhD-Dissertation / Industrial part is Gabriel, Kolding School of Design, 2011).

35 The price for furniture textiles bought at the store was 60-110 kr/m2; the price for the used Geotextile was around 11 kr./sqm. The prices are not readily comparable because 520 square meters of Geotextile was bought and only a few square meters of furniture textiles.

36 The hydrostatic formwork pressure is relative to the height of the pour. Following the rule of thumb, the 60 cm high pour of the Ambiguous Chair can be calculated as follows: $P\ [kN/m2] \approx 0{,}01 \times \rho c \times H$; $P = 0{,}01 \times 2000 \times 0{,}6 = 12\ kN/m2$

37 This specific project was interrupted but may continue in another form (e-mail from Professor Håkan Torstensson, Borås School of Textile, 2011-11-14), Anna Lundahl and Katarina Malaga, "Use of Technical Textiles to achieve Bio-Inspired Surface Structures of Building Facades," in *Proceedings of the COST Strategic Workshop* (presented at the Principles and Development of Bio-inspired Materials, Vienna, Austria: BOKU – University of Natural Resources and Applied Life Sciences Institute of Physics and Materials Science, 2010).

Roles of the textile in the Ambiguous Chair

Furniture textiles are characterized by a close relationship between instrumental and rhetorical properties.[34] Instrumental properties include high tensile strength to avoid deflection from heavy use over decades and coloration by durable dyes. Rhetorical properties include the pattern design, the materiality and the tactile properties. Furniture textiles have patterns to be seen and physically felt at the same time. These aspects have practical consequences – patterns are repeated in scales determined by use. Similarly, the width of the rolls of textile is determined by the conventional scale of use; the price of these textiles is higher than the price of industrial polyolefines.[35]

The rhetorical role of the textiles used in the *Ambiguous Chair* reflects upon material selections for the formwork based on scale and function. The low formwork pressure of 12 kN/m2 at a 60 cm high pour[36] and the chosen restraint method allow for a wide range of textiles to be used as formwork. In order, however, to achieve the discussed ambivalence in the expression of the chair, emphasis was placed on the selection of textiles with distinct patterns and textures associated with furniture.

The experimental *Ambiguous Chair* series uses the generic structural-technical properties of the furniture textiles but places particular emphasis on the specific symbolic and sensed qualities associated with fabrics and upholstered furniture and inserts concrete into this familiar context. Textile motifs have been transferred to the concrete surface of a 'soft' form and sparked confusion and curiosity about a material (concrete) and a construction method using fabrics.

POTENTIALS FOR TEXTILE NOTIONS AND PRINCIPLES

As mentioned, the use of furniture textiles was related to the architectural interpretation of the literature study of fabric formwork and included aspects of scale, context, and function. But how to discuss the potential notions and principles of furniture textiles in architectural concrete structures?

A chameleon changes the appearance of its skin to fit a surrounding habitat. Concrete is like a chameleon, changing its skin (once) to fit the surrounding formwork; the 'habitat' in this case is defined by the maker as the function and appearance of a chair. The issue of this type of textile potentials can be categorized as symbolic representation with varying degrees of instrumental robustness. At the 'low end' of the instrumental scale, this could be understood as pure expression of textile symbolism interpreted as a 'chameleon-like' decoration of a concrete surface.

An example of a completely instrumental approach to textiles and concrete surfaces aims at designing textiles as form-liners for rigid formwork to add hydrophilic properties and create a dirt-repellant surface.[37] The use of furniture textiles for the experimental series added a distinctly decorative aspect to the structural role of the formwork textile. This points directly to the continuous search for new expressions for concrete surfaces and is more related to the use of textile as metaphor and ornament in architecture than to the structural potentials of textiles in formwork. Textile C's decorative pattern of velour patches has been glued on to the cotton weave, a post-treatment done by the manufacturer. The transfer of material to the concrete surface from the textile is based on the adhesive, which seems to dissolve in the alkaline environment of the pour, and aided by the fuzzy fibers of the patches. In this purely technical regard, the transfer of fibers or chemical particles in controllable, specific areas through 'delamination' during the pour is a very relevant topic of further exploration. It is related to the technology of the product Graphic Concrete,[38] which prints retarder chemicals in graphically designed patterns on paper sheets to lay in the molds for prefabricated concrete elements. At the 'high end' of the dual-sided technological scale, the use of a specific pattern or imprint for specific forms contains decorative potentials.

The textiles A, B, and C used in *Ambiguous Chair* were partly selected for the expressed character of their surface. Even the slightest changes in the direction of the weave in the construction of the formwork textile had direct consequences for the cast concrete surface. This aspect could be researched further with a view to exploring the aesthetic potentials.

On a textile construction level, the manufacture of the textile may be designed to prepare for the construction procedures. The textile could be manufactured to indicate and reinforce points for form-ties.

Design for haptic encounters

The fabric-formed concrete surfaces developed in the *Ambiguous Chair* series have been discussed in two specific projects for their specific tactile or haptic qualities.

The concrete surfaces of the *Ambiguous Chair* were used in specific planning proposal for an ambitious office building for the Disabled People's Organizations of Denmark.[39] Concrete surfaces in the building were designed to be experienced haptically as one of multiple ways of navigation to accomodate all users despite handicaps. Surface variations in the concrete structure of the building would serve as tactile direction indicators and become an embedded part of the load-bearing structure and architecture of the office building. This focus on specific needs of end users illustrate how architecture is experienced by means of other sensory systems besides vision.[40]

The construction of thin concrete shells cast in furniture fabric was proposed for a design and planning proposal for an interior 'sensing installation' for a residential home for people with severe mental impairments who would receive stimulation from touching the surfaces of undulated concrete screens and listening to sound installations. At the same time, this installation would be part of the architectural surfaces of the building.[41]

Following these discussions the author has performed three experiments to investigate the transfer of textile patterns from fabric as form-liners in rigid formwork cast horizontally as elements and in a concrete wall cast in situ.

Textile patterns in horizontal formwork

Small-scale tests were prepared in regard to prefabrication of rectangular concrete elements. Rigid molds were prepared with patterned 'hobby' textiles as form liners and cast horizontally.[42] The small-scale tests were cast with a 4-8-mm aggregate mix delivered by truck. The surfaces showed a satisfactory transfer of patterns, but the surface quality of the concrete was not as good as the textiles used as permeable formwork, and the formwork was difficult to remove from the surface.[43] (Illustrated on the previous page)

38 See "graphic concrete", n.d., http://graphicconcrete.com/. In Denmark the technology is used by the concrete element factory Confac, www.confac.dk

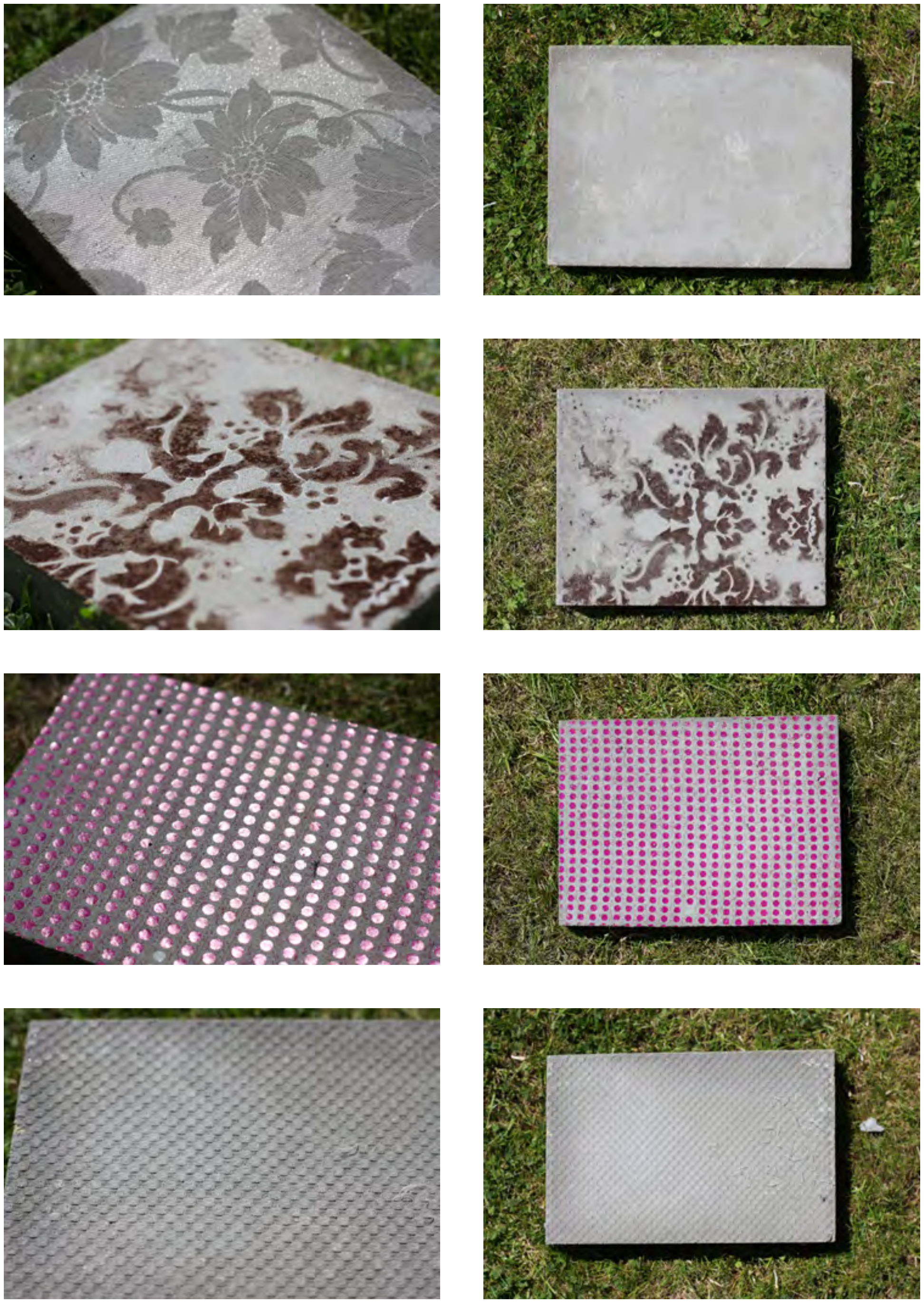
39 In a dialogue with colleagues at E.Pihl & Son.

40 Juhani Pallasmaa, *The Eyes of the Skin: Architecture and the Senses*, 2nd ed. (Academy Press, 2005), 42. Pallasmaa refers to the perception theorist James Gibson: "*Instead of the five detached senses, Gibson categorises the senses in five sensory systems: visual system, auditory system, the taste-smell system, the basic-orienting system and the haptic system*"

41 With CEO of the indudustrial design company AKP Design, Annette Krath Poulsen, October 2009. This principle was developed further and tested at the Erasmus Summer School, 2010, the Furniture Elements (Appendix, workshop 7)

42 Ten formwork frames were prepared for casting outside during the pour of the 2010 TEK1, March 2010.

43 The concrete surface quality of the two experiments cannot be directly compared here, because neither the concrete mixes nor the concrete pours were similar.



Concrete surface samples cast by the author during TEK1 2010. The top sample was the most interesting because the pattern stood out in certain light conditions.

Details of 'tribal' and 'butterfly' concrete surfaces, tests by the author (Vermont Wall, 2009 / Appendix: 4)

The top images illustrate the most interesting and subtle surface. It only had visible patterns under certain light conditions where as the most 'fun' surface showed a transfer of colored sequins. This could, however, also be achieved more simple as a post-treatment to a concrete surface.

Textile patterns in vertical formwork cast in situ

Two small tests were carried out in the context of a workshop construction of an on-site pour for a small house in Vermont.[44] A velour-printed polyester was mounted on a rigid formwork element, a so-called block-out, to create a doorway. As with textile C in the *Ambiguous Chair*, the adhering agent for the velour pattern dissolved, and the pattern transferred directly to the concrete surface, leaving the threshold with a significant black pattern and soft touch. Additionally, a polyester textile with a subtle woven pattern was mounted on a permeable woven polypropylene textile on a rigid board. The textile did not adhere to the geotextile and was lost into the pour; the textile that was mounted on a rigid board stayed on but left only a very subtle imprint of the pattern.

The three experiments should be seen in a larger context. The effect of the textile transfer to the concrete surface is experienced and recognized as an aesthetic feature because of the aesthetic textiles. The principle of transferring precisely defined formwork surfaces deserves additional attention and research and may be discussed in regard to obtaining specific surface properties for concrete during the pour, which may be aesthetic or technical.

Practical improvements for the experimental formwork

The *Ambiguous Chair* series was constructed to test the formwork principle on a small scale. Simple improvements of the procedures of the pour and of the properties of the rig, the textiles, and the reinforcement placed in the formwork could strengthen the specific casting procedures and the result, if a similar experimental setup was attempted in the future.

The rig for the *Ambiguous Chair* is a simple thing to improve; a plywood sheet in the rig for the ∂-shaped chair was too thin and bendable, which proved fatal for the pour.

Textile A, the leaf-patterned textile, left a pleasing and subtle effect on the concrete surface but the thin polyester textile was easily damaged[45] during the construction of the formwork. This property of the textile may furthermore have led to blown form-ties and other mishaps during the pour of the ∂-shaped chair.

Broader washers would provide increased stability but also have a stereogeneous consequence similar to an impacto.[46]

The rigid reinforcement structure inside the formwork for the S-shaped chair may have provided rigidity to the formwork structure during the pour. It would be interesting to further explore this role of the inner structure to assist in both the pour and as reinforcement.[47]

Discussion of textile properties

Based on this analytical study it would be relevant to discuss which textile properties could be further developed in order to strengthen the material appearance or the aesthetics of fabric formwork.

44 An L-shaped wall for a cabin was constructed during a fabric formwork workshop organized by ISOFF members Sandy Lawton and Mark West at Yestermorrow Design Build School in Vermont, USA, June 2009. A visual summary is in the appendix.

45 A slip of the hand holding the scalpel for preparing the last tie-holes.

46 The small washer 'disappeared' and left no impacto marks on the concrete surface.

47 This would complement Kenzo Unno's system for building planar walls

First, let us recapture which textile properties are transferred to concrete in the experimental series of the *Ambiguous Chair*

The stereogeneity of the *Ambiguous Chair* expresses general characteristics of concrete cast in fabric formwork: double-curved (structural) surfaces and tiny creases as a consequence of the material dialogue between textile, rig and restraint.

Specific material properties such as the pattern of the weave of the three different textiles were transferred to the concrete surface; some fibers were even embedded especially in the ∂-shaped chair. The golden fibers of the leaf-patterned textile were transferred and added a golden sheen to the concrete surface, and fuzzy fibers from the velour-stamped textile left the concrete feeling as well as looking soft.

In order to obtain a stronger sense of materiality and tactile comfort for the appearance of the *Ambiguous Chairs* one could emphasize a further development of the restraint method for a more ergonomic design, perhaps by impacting a shape to accommodate a sort of cushion placed on the concrete seat. In order to emphasize a stronger sense of textile notions in the stereogeneity, pleats and creases could be introduced into the formwork, either through the preparation of the form-tie holes or through the tensioning of the textile in the rig.

Conclusion

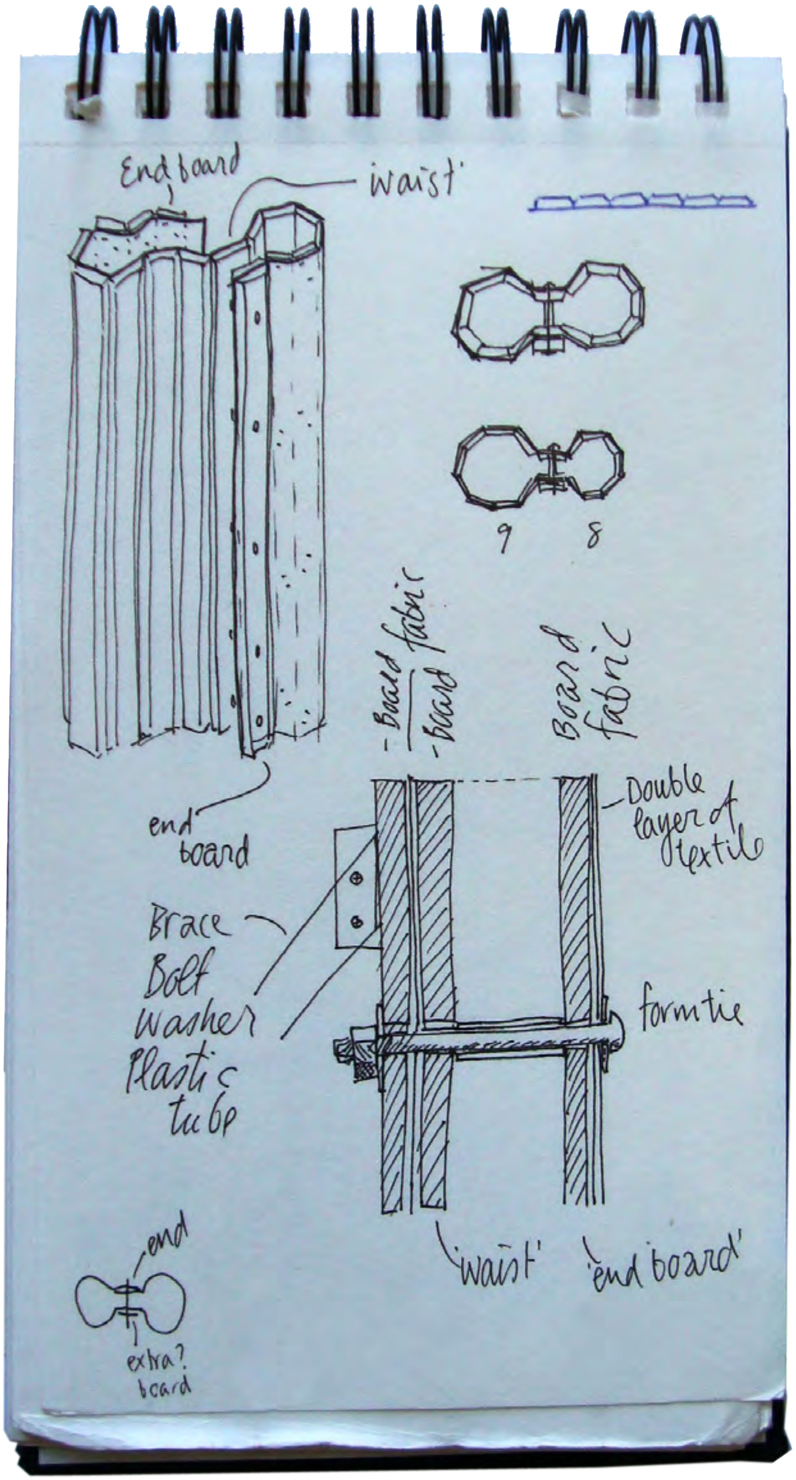
The use of furniture fabrics in casting concrete sculptural objects has proven an effective way of illustrating principles of fabric formwork; the *Ambiguous Chair* series could only have been cast in textiles.

Through the ambiguous appearance of the 'chair,' the series has challenged observers' conceptions of concrete and drawn them into a dialogue about the potentials of concrete.

These mainly rhetorical aspects of the textile notions were closely related to the exploration of an implied oxymoron in the experimental case. The responses at the primary exhibition venue confirmed the validity of this strategy with regard to generating a discussion of the technology, but the ambiguity also blurred the technical aspects and potentials of the formwork technique. The chair as a specific functional typology served as a crucial frame for both of these aspects.

STUDY OF THE COMPOSITE COLUMN

Author: Anne-Mette Manelius
with assistants Jannie Bakkær Sørensen and Signe Uldfeldt
Where: RDAFASA
Year: 2010
Context: TEK1 Workshop


End board
'waist'
9
8
Board fabric
Board fabric
Board fabric
Double layer of textile
end board
Brace
Bolt
washer
Plastic tube
formtie
'waist'
'end board'
end
extra? board

STUDY OF THE COMPOSITE COLUMN

Structural typology of concrete	Collumn
Structural typology of formwork	'Vertical lath'
Role of fabric in formwork	Embracing
Types of restraint in formwork:	Ties through planks
Reinforcement	One 6-mm rebar
Concrete type	Small aggregate, 4-8 mm
Concreting procedure	Pour (from truck)
Short description of formwork principle	2-meter tall facetted column structure cast in a prefabricated pile jacket of 'wood plank textile' and braced vertically.

Eg

This study focuses on the *Composite Column*, for which a pre-made wood-textile composite, consisting of wooden formwork boards and a woven polypropylene textile, form the basis for a structural formwork principle to produce facetted concrete forms and wood imprints on concrete structures.

The *Composite Column*, constructed at TEK1, 2010, was an exploration of simplified construction. It is a two-meter tall concrete column with 'angled sides' and surface imprints from wooden formwork boards. The column is part of the author's second series of experiments, which explored embracing structural textiles, focusing on the forming and structural roles of embracing textiles in fabric formwork.

This experimental series also includes the *Chalmers Column*,[1] shown to the right and constructed during the Concrete Flesh Workshop[2] in 2009. This experiment was a sculptural exploration of embracing netting jackets, based on early sculptural explorations by Mark West, [3] and impactos. The hung formwork consisted of an inner tube of expandable spandex and an embracing outer 'jacket' of glass fiber reinforcing net. The small openings in the glass fiber weave and larger openings cut with scissors allow the inner tube to bulge; the bulging was contrasted by impacto block-outs[4] constructed with round, conically layered plywood discs.

Chalmers Column (Appendix 5.1)

Wood-textile composite formwork for the *Seal* prior to concreting (See appendix 2.5)

Wood or textile facing the concrete

The ambition of forming *facetted* concrete surfaces in a fabric form was initiated by students with the *Seal,* TEK1 2009[5] illustrated to the right.

The student experiment *Seal* constructed a wood-textile composite to create geometries that could not be obtained with fabric alone. The textile side of the wood-textile composite faces the concrete as in conventional fabric-formed concrete.

In the formwork principle for the *Composite Column*, the wooden side of the composite

The *Seal* (Appendix 2.5)

fabric faces the concrete with no traces of the textile.

For the *Composite Column*, the description of the formwork principle and the construction procedures of the *Composite Column* are followed by a comparison between the stereogeneity of the column and the *Seal*. This is done to clarify, compare, and discuss the different roles of textile in fabric formwork when the used textile merges properties of rigid and flexible materials.

Formwork Principle for the Composite Column

The formwork principle in the *Composite Column* is based on the construction of a composite textile; a geo-textile is used as the backing material for parallel formwork boards (10 cm wide).

The formwork principle is a 'jacket' that is closed with buttons (ties) in the 'waist.' The textile side of the composite textile will act as an *embracing* agent in the formwork structure.

In the experiment, the principle is tested in connection with casting irregular geometries in a structure formed by the combination of convex and concave shapes. This constitutes the formal principle for the irregularly dimensioned column.

The wooden side of the composite textile will face the pour and form a column, which is the connection of two similar columns yet with quite different geometries. The concrete form will be facetted, and the surface is marked by the distinct, traditional wood pattern of the formwork boards.

CONSTRUCTION

The composite textile

- Formwork boards are prepared, cut in lengths of 210 cm with a 'tapered' top.
- Boards are aligned and distanced. The dimensions and distance between the boards influence the dimensions of the piece; the closer the boards, the smaller the ratio of 'hinging' between the boards. The distance between boards is approximately one centimeter, adjusted to allow the composite textile to curve and form a circumference tube of seven boards.[6]
- Textile is placed on boards and stapled

Construction of the Composite Column

- The desired circumference for the pair of columns defines the length of the composite textiles according to the equivalent number of boards.
- The 'waist board' and 'end-board' are located, and using an extra board as template, holes are drilled for ties.
- The braces/frame is prepared to keep the formwork steady and vertical.
- The formwork jacket is closed; the end-boards overlap, and the extra board is placed behind the 'waist-board'.
- The extra board acts as part of the frame.
- *The Pour* is done using concrete delivered by truck, alternating between filling parts of each side (each column) of the formwork.

1 With Norwegian architect Kathrine Næss and Danish architect, Frederik Petersen, then a PhD scholar at the Aarhus School of Architecture. The experiment formed part of his thesis work for "Repræsentationens realisering" (PhD-Dissertation, Aarhus School of Architecture, 2011).

2 Morten Lund, Sanna Nordlander, and Karl-Gunnar Olsson, eds., *Concrete Flesh - Matter Space Structure Studio Workshop November 2009* (Gothenburgh, Sweden: Chalmers University of Technology, Dep. of Architecture, 2010).

3 Columns from College of the Atlantic, 1992 and Casa Dent, 2001. n.d., www.umanitoba.ca/faculties/architecture/cast/research/fabric_formwork/columns.html; Cheng Design, *Casa Dent*, Architecture, House, 2001, Culebra, Puerto Rico, www.umanitoba.ca/faculties/architecture/cast/assets/downloads/PDFS/Fabric_Formwork/Casa_Dent.pdf.

4 Understood as a combination of the formal stamping effect of an impacto and the perforation from the block-out.

5 See appendix, 2.5

6 If the distance were smaller the circumference would become larger.

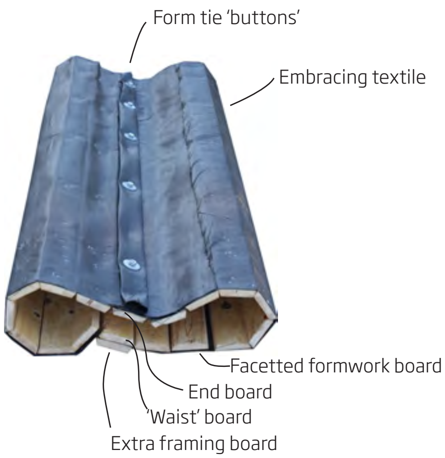
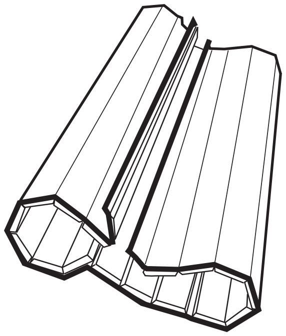


Image of the closed formwork jacket for Composite Column illustrating the terms of the formwork element

Top: The formwork jacket ready to close - prior to this the fabric was stapled to the formwork boards

Middle: Tubes used as clamp spacer - The jacket is ready to be buttoned. Notice tapered wooden boards

Top right: Before the pour
Formwork ready for the pour - the jacket is simply standing on the formwork boards and fastened only by one connection.



After the pour. Notice the bit of concrete at the bottom that leaked during the beginning of the pour and wrinkles in the fabric. The vertical, grey lines are water and cement paste gone through the fabric between the inner formwork boards.

Composite Column, the concrete structure appears facetted and show no traces of textile. Notice the detail from the 'end-board' in the middle

Striking the formwork

The jacket is 'unbuttoned', and the concrete is undressed.

Concrete has filled the space between the fabric and a waist board, necessitating an effort to remove concrete in order to remove the board.

STEREOGENEITY

The Stereogeneity of the Composite Column

The concrete structure consists of two convex areas separated by a concave part, the 'waist'. The structural typology is a column. It has facets of identical dimensions and imprints on all the vertical surfaces, which indicates that the concrete structure has been cast vertically and that wooden boards had acted as signifiers, defining the geometric form and surface character of the concrete column. The waist in the middle of the column gives an impression of symmetry, but the two convex sides of the column are not identical. When seen from above it is obvious that one side is larger than the other. The angles between the facets vary; one side simply has one more facet with imprints from formwork boards. (See images).

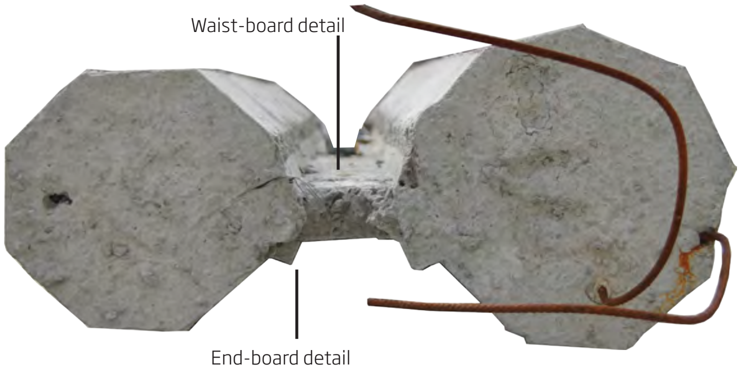
Five clamp holes appear at uneven intervals at the vertical 'waist' of the column; the holes are placed closer near the bottom, which illustrates the higher formwork pressure at the bottom. The stereogeneity of the column shows no indication that textiles have been part of the construction process. The stereogeneity of the column is the expressed construction of a planar geometry based on 10-centimeter wide wooden formwork boards.

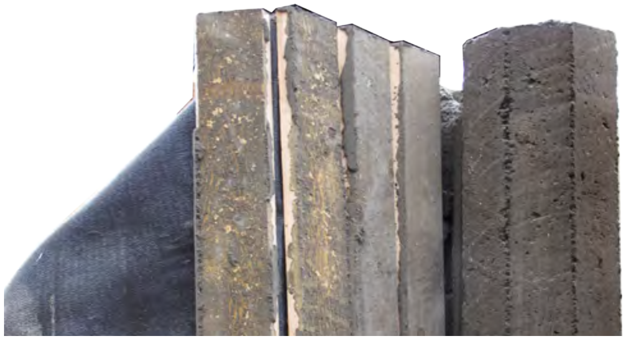
The Stereogeneity of the Seal

The *Seal* was concrete cast into the textile side of a wood-textile composite. The object appears as a cast solid, but in regard to the expressed process of the specific formwork-tectonic construction, Eduard Sekler would use the term *atectonic* due to its blurred manifestation of the applied structural principles. The *Seal* is a crystalline sculpture, and its *stereogeneity* reveals the facetted concrete form expressing the geometry of something rigid. Thus, one cannot be certain whether the concrete element was cast in a rigid form that was milled, built by a carpenter, or whether it was cast in a membrane.

At a closer look at the concrete surface shows imprints of the woven polypropylene textile that faced the pour, indicating that a flexible membrane was part of the construction.

A further examination of the concrete structure reveals forms that could not have been cast in rigid formwork; rigid forms could have been filled, but if rigid, the formwork could not have been removed from the cured concrete in one piece. In this sense, the structure reveals its *geneity*, the fact that it was formed by flexible formwork. The concrete form and surface expresses topological nuances of an additive geometrical principle.





Composite Column, a detail image of the concrete surface shows imprints from the wooden formwork boards. Notice the detail from the 'waist-board' in the middle

The *Seal*

Top left : Composite Column, the concrete structure seen from the top. It is obvious that the right side of the column is larger than the left. The geometry of the left side is recognized as symmetrical.

Top right: Detail of Composite Column during the 'stripping' of the concrete structure; the formwork jacket is open and shows the composite textile (embracing textile and the formwork boards);

Middle right and bottom : The Seal, TEK1 2009. Image of the facetted concrete shows a form that could not have been cast in a rigid form. The detail below shows imprints of the woven textile that faced the concrete.

ROLES OF THE COMPOSITE TEXTILE

The use of textile in the formwork for the Composite Column goes to the *roles* of the textile; the composite of wood and textile has several roles as signifier of form and surface as well as a structural role as the 'embracer'. In order to clarify these different roles, we have to deconstruct the composite, breaking it down to its elements. The wood-textile composite has a wooden side and a textile side; the roles of the two sides will be discussed in the following.

Roles of the wooden boards

The properties of the wooden side of the composite define the possible geometries for the formwork as well as the surface pattern.

The dimensions and application of the wooden formwork boards carry significance. In the experiment, the boards were three centimeters thick and ten centimeters wide; they had tapered tops to enhance the possibility of angling of the boards.

The wooden formwork boards have rhetorical roles as geotextiles for the convex shapes. The 'waist-board' and 'end-board' furthermore have instrumental roles as restraining boards for the form ties. The 'waist-board' also connects the vertical bracing via an additional frame board.

Roles of the distance between boards

The instrumental role of the distance between the boards has relevance for the manageability of the wood-textile composite– tightly placed boards create a large radius for the curvature of the composite; a greater distance between the boards means greater angularity. It should be noted that the 'end-boards' of the wood-textile composite have almost 90° angles to the next formwork boards, and the distance between the boards has no instrumental role here – the angle between the formwork boards does have a stereogeneous consequence, however, and thus plays a rhetorical role – the space between the boards in this open corner is filled and the sides of the boards themselves are left visible in the concrete surface.

Roles of the geotextile

The properties of the textile side of the composite define the tensile strength and the elongation; hydrostatic pressure is transferred differently and possibly unevenly to the surfaces, especially the edges of the formwork boards, and on to the textile. However, these altered properties of the textile still define the strength of the instrumental role of the textile as the structurally embracing agent.

The textile property of flexibility informs the rhetorical role of the composite textile; freely bendable connections between the wooden formwork boards act as hinges that allow for simple alterations of geometric forms.

Due to the particularly instrumental roles of the geotextile, this embracing side of the wood-textile composite is fundamental to the variation of geometries and modifications of the formwork principle. In other words, the textile is the backbone. The formwork boards, which are the geotextiles in this experiment, can be easily replaced with other rigid materials and geometries for other applications.

Instrumentally and rhetorically, the wood-textile composite now has new properties:

- The textile has 'bending' properties according to the width and distance of the boards
- Wooden boards define the concrete form, and the wood pattern define the concrete surface
- Boards become part of the *rigid seam*, serving as a frame that supports the vertical bracing of the formwork during the pour
- Wooden boards become form ties
- The textile back has a structurally *embracing* function

It is a prerequisite for the composite principle that the hydrostatic pressure of fresh concrete press the boards outwards, until the backing, embracing textile is fully deflected. That is why the textile is only stapled to the wooden boards in order to keep these in place during handling, construction and pouring, thus clearly indicating the separation of rhetorical and instrumental roles in the lose wooden boards and the embracing textile.

To test this statement one could simply imagine that the 'wooden board textile' for the *Composite Column* was used with the textile facing the concrete pour, and the wood on the exterior. In that situation, the hydrostatic pressure from the concrete would produce a rounder shape, as the textile deflects with equal force all around the tubular formwork; the concrete surface may show very little indication of the wood; the boards might even pop off, as the textile deflects under the hydrostatic pressure. The instrumental role of the textile is intact, and the rhetorical role of the wooden boards vanishes as they literally pop off.

Top: Concrete defined the distance between formwork boards at the 'end-board'.Image from stripping the concrete. Photo: Signe Ulfeldt

The 'waist-board' was partly embedded in concrete that flowed between the wooden board and the textile.Without the 'extra frame board' this concrete might have acted as on the image above.

Roles of the wood-textile composite in the Seal

Textiles with traditional properties alone could not achieve the creation of a facetted concrete surface. This goes for the *Composite Column*, which has wooden imprints on the surface from the forming agent of the composite textile, and for the *Seal*, which has textile imprints and only forms from the forming agent. The instrumental role of the pp-textile is to serve as a container for the concrete and as a backing material for the wooden discs. The rhetorical role of the textile is to serve as a surface-maker, as the pattern of the weave is imprinted on the surface of the concrete element.

Instrumentally, the *Seal* shows that wood-textile composites can be used as a simple means to produce facetted concrete forms with flat surfaces and sharp edges.

The rigid wooden geometric pattern is the forming agent and carries a rhetorical role; the wooden discs also function as the restraining agent of the formwork and carry an instrumental role, as the textile is embraced. The less than five-millimeter distance between the rigid discs means that a simple force applied to an area of the formwork sheet will affect the geometry of the surroundings.

Seal composite textile formwork with a few restaining 'impac-tos'

Discussion of the wood-textile composite

In the *Composite Column*, the textile is the structural embracing agent; it does not touch the concrete and hence leaves no mark on the concrete. The wooden boards have the role of both form- and surface maker or signifier; the concrete surface carries imprints of the wooden boards.

Improvements of the Composite Column formwork include the detail where the waist-board behind the vertical brace board was embedded in concrete. (Photos: Signe Ulfeldt)

Wood-textile composite by Danish architect Amanda Betz. (Photo courtesy of Betz)

The specific use of a wood-textile composite in the *Composite Column* thus enables a whole range of composite textile principles, in which the forming principle and the structural agent can be two different components.

This aspect was tested in a plaster model,[7] a column that was made with the use of a thin polyester textile as the structural agent, with ornamental features that stemmed from a form-making agent placed inside the formwork.

For the model, pliable play dough was formed; for full-scale construction, articulated inlays could be produced by CNC milling, cast rubber or a number of different materials and manufacturing procedures.

Improvement of the wood-textile composite principle

The backing textile for the *Composite Columns* was stapled to the wooden planks. When the composite textile was removed from the workshop, the boards fell off the textile, and the textile was generally not very easy to handle during construction until the pour. The composite textile could not be easily rolled, it was heavy, and the boards hung from the polypropylene, held in place only by the staples. For future prototypes of the formwork principle, the composite should act more like one material, not as boards dangling from a sheet of fabric. Larger clamps could be used, and the boards could be thinner or made of a lighter material.

For the simple application of the linear principle of the wood-textile composite, the embracing textile could be less flexible, possibly an open net of polyolefin or metal. An embracing net with a rectangular pattern has embedded a kind of measuring units. This could result in easier handling on site compared to a unmarked sheet of textile.

For the construction of the *Composite Column*, the formwork principle worked best when the wooden boards formed a concave shape to generate a convex concrete form; the thickness of the boards and their mutual distance then defines the possible geometries and hydrostatic pressure against the boards and the embracing backing textile. The 'waist' can be treated as a convex formwork space that will form a concave concrete form.

One would expect that the 'end-board' would be the most critical detail. In fact, it was the waist-board that was connected to the vertical bracing that caused the most complications, and which can be considered the weak point in the construction of the formwork principle. An improvement of the applied principle would be to ensure that the surface of the back of the waist-boards could be fastened more evenly to the textile. Removing the space between the board and the textile would further reduce the risk of embedding the waist-board in the concrete.

A simpler solution would be to simply remove the inner waist-boards from the formwork. That would remove the risk of embedded boards and instead reveal the embracing textile and emphasize the hinge-like connection between the column elements. This would add a textile appearance to the surface and would also serve to strengthen the materiality of the wood-textile composite. In such an alteration the textile should not be open as suggested above.

The design of the forming elements of the textile formwork principle could be more varied. A number of unique patterns and reliefs can be achieved by altering the surfaces of the boards, their geometry, their bending properties,[8] and their positions. The Danish architect Amanda Betz has developed a wood-textile shown on this page with such properties for an exhibition as part of an investigation in folds.[9] An addition of this level of customized complexity to formwork requires additional investigation as well as solutions to various issues related to the occurrence of an embedded waist-board.

7 By Anne-Mette Manelius and architect and Industrial PhD-scholar Johannes Rauff Greisen (co-organizer of TEK1 workshops).

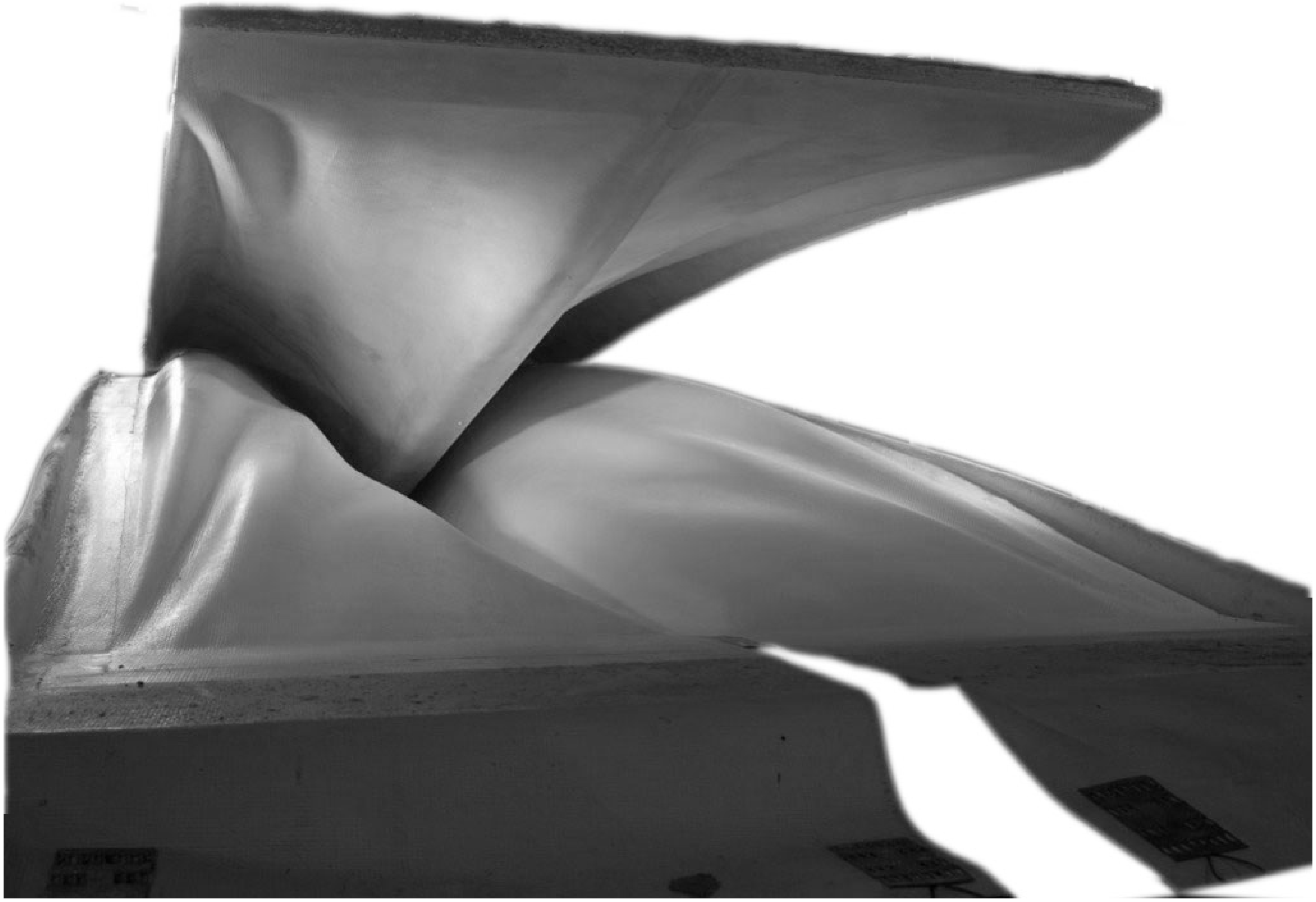
8 By using boards of different thicknesses.

9 Rasmussen, Peter Møller, Maria Mengel, ida Flarup, and Thomas Feveile, eds. Modtar Projects 2007-2010. Copenhagen, Denmark: Modtar Projects, 2010. A Betz' piece is related to a number of investigations of folding architecture. The topic of folding formwork has been investigated in the experiment 'ReVault' as part of the PhD project about tectonics and concrete by the Danish architect Ole Egholm Pedersen at Aarhus School of Architecture, Denmark.

STUDY OF THE FABRIC-FORMED RIGID MOLD

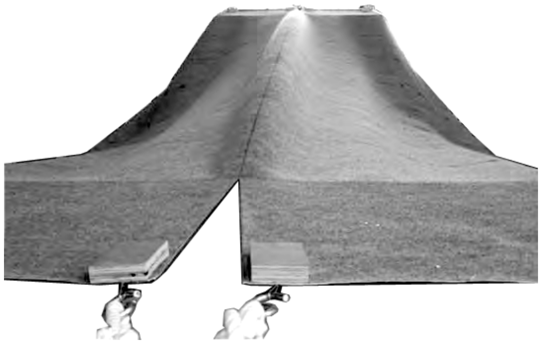
Author: Center of Architectural Structures and Technology (CAST)
Mark West, Ronnie Araya and staff

Where: CAST at the University of Manitoba, Canada
Year: 2009
Context: Prototype



STUDY OF THE FABRIC-FORMED RIGID MOLD

Structural typology of concrete	Experimental Prototype
Structural typology of formwork	Shell
Role of fabric in formwork	Rig
Types of restraint in formwork	Tensioned
Reinforcement	Fibers and textile
Concrete type	Glass Fiber Reinforced
Concreting procedure	Thin layer, 'hand padding'
Short description of formwork principle	5,4 meter long, thin double-curved shell structure cast in a fabric-formed rigid mold. A specific textile has several roles in the formwork over time. First it functions as stay-in-place formwork and then as formwork surface



The *Fabric-Formed Rigid Mold* was created at the research laboratory of CAST (Center for Architectural Structures and Technology) at the University of Manitoba in Canada in 2009. It is part of a series of investigations at CAST into corrugated structures obtained by tensioning and manipulating textiles in a rig.

The *Fabric-Formed Rigid Mold* is a 5.4 meter-long prototype based on a sequence of casts. In the first cast, a particular fabric is used to form a thin corrugated rigid mold. In the second cast, a thin concrete shell is cast from the rigid mold.

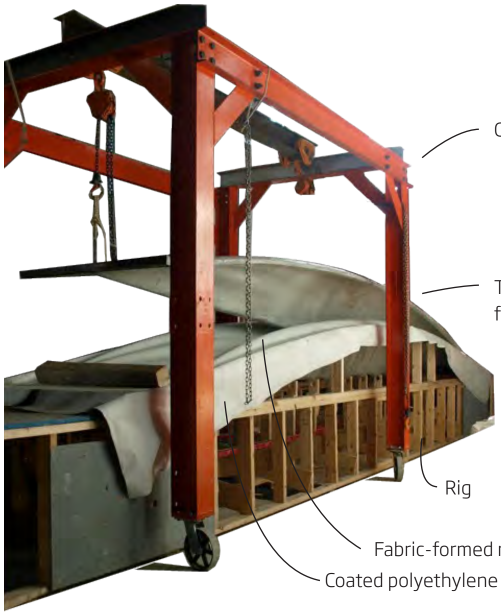
This example is the most complex of the experiments studied in this thesis, as the prototype is developed through a sequence of forming and casting procedures and not singular fabric-formed procedures. Furthermore, the construing of the formwork principle builds upon decades of artistic practice[1] and architectural research, and the construction of the prototype combines precision craftsmanship with contemporary technologies of concrete reinforcement, specialized textile production and measuring tools.

The methodological research sequence that was applied at CAST follows from a series of construction of models based on textile wrinkles[2] and the combination of textile buckles and concrete: Small prototypes are created in 'small-scale,' 'domestic' textiles, where material behavior is observed, as the textiles are manipulated to produce wrinkles. Next, these wrinkles are 'frozen' in models using small-scale textiles and plaster. And finally, industrial textiles and concrete are used for large-scale prototypes.

Based on an examination of these aspects, this analytical study discusses how a particular textile behavior, in this case textile wrinkling, transfers to concrete. What are the technological roles of the textiles used in this prototype, in what ways does the application of a specific composite textile change the previous technological roles of the textile in fabric formwork, and what are the consequences for the resulting building of applying a textile vocabulary for concrete?

1 On Mark West's practice as an artist since 1980, see CAST, "CAST :: CV Mark West", *About Mark West, director at CAST*, u.d., www.umanitoba.ca/cast_building/people/mark_west.html.

2 Textile buckles are understood as the folds and wrinkles and should not be confused with the physical deformation called buckling.



The felt-fabric is very difficult to rip off a concrete surface. Right, fabrics at the CAST laboratory.

The structural formwork principle for the rigid mold is based on a general and a specific aspect of the composite formwork textile.

Generally, textiles develop drapes or wrinkles when they are tensioned between points. Specifically, each side of the specially manufactured composite textile behaves in a particular way during the different conditions of concrete that occur as part of the experiment. First, the felted side of the textile is used as stay-in place formwork for a rigid mold. The mold is flipped, and a second, thin concrete shell is cast against the coated textile surface of the rigid mold.

The experimental data for this analytical case includes documentation of the textile principles, of the production of the rigid mold cast in fabric-formed concrete, and of the thin concrete shell cast in the rigid mold.[3] All images are courtesy of CAST unless stated.

To the author's knowledge, the shell has not been structurally tested, and the focus of the analytical study is on the roles of textile in the various conditions between structural formwork principles, construction process and stereogeneous structure.

CONTEXT

While West's sculptural work during the 1990s can be characterized as explorations of conceptually 'softening' concrete and expressing its liquid origin (related to Miguel Fisac's work), recent explorations of textile wrinkles at CAST are examples of the opposite approach to fabric and concrete: the self-organization of the textiles, which has lead to studies of the transfer or 'rigidization' of soft textile forms. These studies have been based on hanging draped sheets, which have then been manipulated and pulled to create tensioned buckles and finally 'rigidized' with thin layers of sprayed concrete.

Form-finding

The context of the *Fabric-Formed Rigid Mold* includes an interest in the experimental form-finding practice of the Swiss engineer Heinz Isler (1926-2009). West sees a discrepancy between Isler's intuitive form-finding methods for form-efficient thin-shell structures and the subsequent need to build large wooden rigid falsework to support the concrete and steel for the structures in large scales. West has hypothesized that it should be possible to produce "fairly large vaults just directly from hanging the fabric and making the mold from the fabric."[4]

Fuzzy-backed textile

The specially produced so-called 'fuzzy-backed'[5] textile is a composite textile, where two different textiles have been heat-welded together, so that their properties are combined. The 'fuzzy' side is a felted textile with a wool-like feel and large fibers; when the fabric is used as formwork the fibers are embedded in the concrete, which makes it difficult to subsequently strip the fabric from the concrete.

The smooth side of the textile is woven polyethylene with a coated, waterproofed front;[6] it slips easily from the concrete and leaves a smooth surface behind.

3 Mark West, "Thin Shell Concrete From Fabric Molds" (CAST, University of Manitoba, 2009), CAST; Mark West and Ronnie Araya, "FABRIC FORMWORK FOR CONCRETE STRUCTURES AND ARCHITECTURE" (presented at STRUCTURAL MEMBRANES 2009, International Conference on Textile Composites and Inflatable Structures, Stuttgart, Germany: CIMNE, Barcelona, 2009, 2009), 4; Mark West, "Heavy Light - Fabric-Formed Concrete Structures", Youtube (Recorded lecture, ETH, Zürich, Switzerland: Institute of Technology in Architecture, Building Structure, 2011), www.youtube.com (Accessed 4-11-2011); Mark West, "Chalmers Lecture about Fabric Formwork" (Lecture at Concrete Flesh - Matter Space Structure Studio Workshop Seminar, Gothenburgh, Sweden, November 2009).

4 In West's lecture at "Concrete Flesh".

Drapes and Wrinkles

The specialization in fabric formwork at CAST includes a wide range of explorations of the self-organization of textiles under various applications of tension from the formwork principle and from the concreting procedure. Thin-layering concreting procedures (spraying and hand-padding) influence the character of the study, because less concrete results in less deformation of the textile. This allows for an exploration of drapes and wrinkles. Like the behavior of textile under hydrostatic pressure, the pull-buckles and push-buckles illustrate a structural behavior of textiles that can be described as 'self-organizing.' The specific textile properties and behavior of a textile tensioned between points are described at CAST as 'Pull-buckles;' similarly, 'Push-buckles'[7] occur when the textile is pushed together on a flat surface.

A previous experiment at CAST involved a combination of push- and pull-buckles and described a certain level of manipulation of 'natural' forms. A sheet of textile is suspended loosely between the two sides of a frame, and a central 'spine' is achieved by draping the fabric over a tensioned nylon cord.[8] This cord under the hanging formwork membrane can be described as an *impacto*. Here, the impacto differs from the stamp-like presence in poured concrete. Thin layers of concrete make the fabric rigid, so that it can be manipulated and draped.

The 'fuzzy-backed' textile has been used in series of prototypes for fabric-formed rigid molds that have two sets of casting procedures in common. First, the textile is prepared to self-organize into drapes by being hung or manipulated via pull- or push-actions. The fuzzy side of the fabric is embedded into *sprayed* or handplaced GFRC (Glass Fiber Reinforced Concrete).[9] The weight of the concrete increases the corrugation of the textile and makes the structural shape rigid. Next, this rigid fabric-formed mold is flipped, and the smooth side of the fabric is now used for possible repeated casts in the smooth side of the corrugated rigid mold.

CONSTRUCTION OF FABRIC-FORMED RIGID MOLD

In short, the construction process can be explained as follows: Pull-buckles are created in the fuzzy-backed textile; the textile is 'frozen' with the fuzzy back facing the cast padding of a thin concrete shell. When the shell is flipped, the smooth side of the textile becomes the smooth surface of a rigid mold for repeatable casts of thin concrete shells.

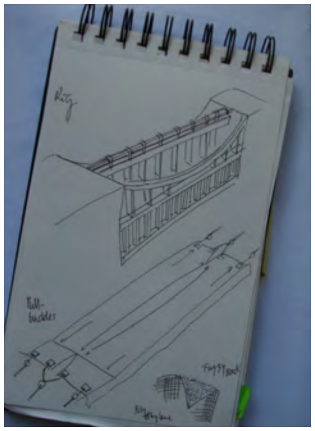
The rig and tensioning

The rig defines the dimensions or the outline of the extremities of the shell element. The sides are shaped as catenary curves; a long metal 'pole' defines the top middle; the ends have straight edges; the ends of the fabric have heavy pull devices using concrete weights and equipped with digital measuring equipment attached to measure the weight (or the tension of the fabric, as one relates to the other).

The textile is pulled lengthwise only to create the longitudinal buckle.

A more in-depth summary of the construction follows on the next page. This summarizes the steps explained by Araya and West in reports and presentations that form the basis for this study.

Left, 'simple'drapes in hung textile. Right, combination of manipulation and self-organization. The mold for this shell was given a deep central "spine" or ridge by draping the fabric mold material over a Nylon cord.



Rig with 'spine', and pull-action on composite textile. (sketch by AMM)

5 Named by CAST researchers after the fuzzy character of felt, which is distinct from the smooth woven and coated fabrics that are otherwise explored. The product name of the textile is Fabrene W756 West, "Thin Shell Concrete From Fabric Molds", 13.

6 "CAST has developed, with Fabrene Inc., a coated, polyethylene fabric specifically made for this mold making application. Woven, high density, polyethylene or polypropylene fabrics can be manufactured with a smooth waterproof coating on one side, and a fuzzy non-woven fabric welded to the other side." From slide presented by Ronnie Araya at the Structural Membranes conference, Nov 2009

7 Push- and Pull-buckles are named by the CAST researchers

8 West, "Thin Shell Concrete From Fabric Molds", 35.

9 Referred to by Mark West as 'cow-shit concrete,' for example during Concrete Flesh Workshop in Chalmers, Sweden in November 2009, to describe the workability and materiality of this kind of concrete mix.

Illustrations of the construction of the fabric-formed rigid mold. (West 2009)
Bottom: Views from beneath formwork rig show the preliminary shape of the fabric sheet before it is loaded (left), end after it has taken the full weight of the wet GFRC (right). The weight of the concrete gives the fabric sheet its final structural geometry. (West 2009, 15)
Bottom : Rotating the rigid mold

Illustrations of the construction of the thin concrete compression shell cast from the fabric-formed rigid mold.

Next page, images of the finished thin shell and details ofthe shell cast from one half of the mold, which indicate the section, the thickness and right, the surface of the coated side of the fabric-formed rigid mold

Making the Fabric-Formed Rigid Mold

- The fuzzy-backed textile is prepared with slits for increased precision in the wrinkling and reinforced pull-points. These points are basically wooden disks with wires and weight sensors attached.
- The textile is placed with the fuzzy side up, so that the long fibers will be embedded in the concrete.
- The textile is pulled from both ends
- GFRC (glass fiber reinforced concrete) is applied to the surface by hand
- A metal bar is added for stiffness
- Padding tubes (made of foam) are added across the structure for cushioning and protecting the structure during handling
- The rigid fabric-formed mold is lifted from the rig
- The rig is replaced with another rig that supports the rigid mold.

The advanced geometry of the structure requires care and attention to make sure that an even layer of concrete is applied to the rigid mold. Weight sensors are attached to the fabric, and the thickness of the concrete layer is controlled.

Making a corrugated concrete shell from the rigid mold

The rigid mold now has the smooth side of the formwork textile facing up. The casting continues as follows:[10]

- A thin-face coat of white concrete is sprayed onto the surface of the form
- Mortar 2-1;
- Steel rebar;
- 2 layers of glass fiber;
- Steel cable; an anchor for handling the shell with a crane[11]

STEREOGENEITY OF SHELL CAST IN RIGID MOLD

The resulting structure is a thin shell. The shape can be described as suspended between the flat linear ends and the linear spine that runs down the middle. The sides are standing funicular arches, and smooth concrete surfaces are 'suspended' and curved between these edges. Tiny creases have formed in the surface near the corners.

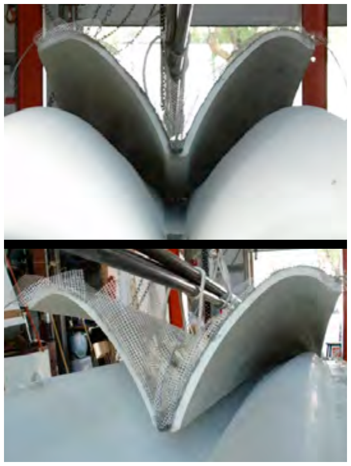
West describes the form of the shell as *resembling* a "*compression vault form,*" and he writes that "*the structural shape combines the geometry of a bending-moment-shaped beam with a tied funicular compression vaults.*"[12]

The height of a bending-moment-shaped beam increases in the middle; this can be compared to the deep corrugated middle section of the shell between the high points of the arch forms and the base of the spine. The spine does not compare to the curvature of the web of a bending-moment-

10 Text accompanying slide images: "White face coat; Mortar 2-1; steel rebar; 2 layer glass fiber; Steel cable," Ronnie Araya's presentation at the Structural Membranes conference, Stuttgart

11 The thin structure is fragile and must be supported when it is not tensioned or in compression. In order to exploit the static behavior of the concrete shell cast in tension, it must be flipped over. The shells have cast-in handles and are further reinforcement to protect them from shear stresses during handling. Both elements can easily be cast into the 'back' of the shell for handling both the heavy rigid mold and the heavy buckled shell.

12 West, "Thin Shell Concrete From Fabric Molds", 12.



shaped beam.[13]

Another naïve comparison would be to describe the form through its resemblance to a pair of 'Siamese twin Gaussian vaults'. The structural behavior of the shape of the shell cast in the *Fabric-Formed Rigid Mold* and a Gaussian vault lies beyond the scope of the material research in the present dissertation. Comparisons will not go beyond the structural appearance of these shapes; instead I focus on the stereogeneity and to what extent the shell expresses its geneity and the technological role of *textile* in this regard.

The shell cast in the Fabric-Formed Rigid Mold offers a different stereogeneous reading than the other analytical cases, because the thin-layering concreting procedure is fundamentally different from a pour. Indeed, the thin concrete structure cannot be read as poured. First of all, the concrete shell does not represent the dichotomy of *concrete-ness*, which Peter Schjeldahl critically describes as the 'promiscuous fluid' and the 'fanatic solid.' In a response to Schjeldahl's critique, Mark West offers a description of the unique 'willfulness' of concrete cast in textiles, where the textile behaves like a dynamic 'resistant' skin:

A struggle ensues. As concrete presses harder against its newfound skin, and the skin tenderly matches each new thrust[SIC] trust with a corresponding strain, see how they surprise each other in their mutual transformation! Their struggle slides into a collective dance, a mutual search for stasis. [14]

The description of this dynamic relationship between concrete and fabric originally refers to poured concrete and an expressed state of equilibrium, and it may serve as an accurate description of the stereogeneity of a poured column, for example. The expression of the shell is more dynamic than static. Even if the form is the structural manifestation of equilibrium with its load, the object *expresses* motion.[15]

The *Fabric-Formed Rigid Mold* displays traces of previous conditions in its structural form; the taut surface almost appears as the result of vacuum suction over a rig; in particular, the central spine of the rig acts as a dominant form-making element, like an *impacto* pressed from the inside or the arching 'rib cage' that is visible in James Waller's Ctesiphon concrete shell system. These shells were cast in situ, and the weight of wet concrete deflected the suspended burlap between supporting arches to create double-curved structures. Additional reinforcement of these shells was unnecessary because of the efficient form and low weight.

TEXTILE ROLES

The *Fabric-Formed Rigid Mold* experiment uses textiles with three different characteristics. The fuzzy-backed composite consists of felt and a woven, coated material; the third character is the open structure of the woven reinforcement textile.

The three characteristics of the textiles used in the *Fabric-Formed Rigid Mold* can be categorized according to the manufacture, fibers and/or treatment as

- 'Fuzzy fabrics' or non-woven felts;
- Open textile of woven glass fibers,
- Composite textiles; and
- Surface-treated textiles.

13 Daniel Sang-Hoon Lee's *Form-Efficient Beam* is bending-moment-shaped.

14 West, "Arrival of Form", 5. trust [sic] in quote

15 In discussing the making of the shell, Mark West describes "how the flat fabric sheet has developed a 'musculature' in response to the loads imposed on it," and he finds an inspirational analogy to the development of structural forms in living systems. West, "Thin Shell Concrete From Fabric Molds", 18.

The *Fabric-Formed Rigid Mold* contains two different uses of fabric formwork as well as different structural roles for the textile. The case has two sets of casting procedures that represent the two general types of concrete construction – one-off vs. serial production. The role of textiles in both sets of procedures is discussed in the following.

Textile roles in the first casting procedure

The fuzzy-backed textile has two roles in the first casting procedure for producing the Fabric-Formed Rigid Mold. During the application of concrete, the flexible exterior membrane serves as the form-maker, as the membrane deflects between the boundaries of the rig, and the self-organizing material turns into a form that is in equilibrium with its load. In the process, the fibers of the felted fabric are embedded in the cured concrete, and the fabric acts as a reinforcement that binds its own coated back to the fabric-formed concrete structure.

Textile roles in the second casting procedure

The second set of casting procedures in the *Fabric-Formed Rigid Mold* case represent the benefits for concrete construction of producing identical concrete elements with advanced geometries from a rigid mold. The serial construction of identical concrete elements cast in rigid molds exploits the liquid state of concrete in the manner of a dumb 'mud pie,' as Frank Lloyd Wright has suggested.[17] There is no material dialogue between formwork and concrete; the concrete simply follows the provided geometric form.

The instrumental role of the coated polyethylene side of the composite textile acts as a smooth surface to produce repeated casts with the second set of casting procedures. In this rigid condition, the rhetorical role of the textile is limited to the post-treated smooth character of its surface.

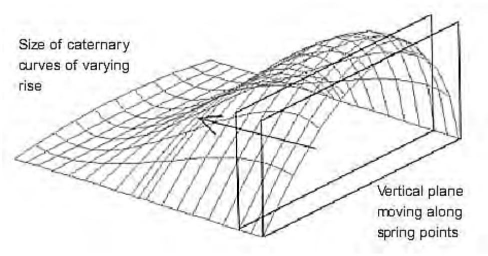
The reinforcement textile is a structural signifier. The shell, which is defined by the advanced geometry of the fabric-formed rigid mold, will be difficult to reinforce without the textile nature of the reinforcement. In other words, shell molds formed by textile properties point directly to potentials for enhancing the textile nature of these reinforcement nets.

This naïve[18] description of reinforcement textiles is mentioned here to point out that the role of the textile can be defined as a second kind of fabric-forming in the course of the experiment.

In the second casting procedure, where a thin shell is cast in the rigid mold, the role of the textile has shifted from creating the exterior *form* to producing the interior *structure*.
In this case, the shell merges the technological significance of a forming and a reinforcing textile, respectively, into a textile solid. Scientific research into reinforcement textiles within the cross-disciplinary field of textile and concrete science, categorized as *textile concrete,*[19] may achieve wider architectural application if the textile notions and principles studied and named in this thesis are combined with the expertise of textile field.

'Concretized' textile – 'textilized' concrete

Similarities between the forming textile and the concrete structure define a unique aspect of the experiment, aside from their nature as composites. Both the composite textile and the concrete contain textile fibers that act as concrete reinforcement, in the form of felted synthetic fibers in the textile and a net of glass fibers in the concrete, which has textile properties



(a) shape of the Gaussian vault; every cross-section is a catenary, but the height varies along the span of the vault. Image.[15]

16 R. Pedreschi and D. Theodossopoulos, "The Double-Curvature Masonry Vaults of Eladio Dieste," Proceedings of the ICE - Structures and Buildings 160, no. 1 (January 2, 2007): 5.

17 F.L. Wright in Writings and Buildings, p. 225.

18 The use of reinforcement textile is limited, and fiber reinforcement does not give concrete structures the same high tensile strength as bars.

19 "Summary of Results for the Project INSUSHELL" (Institut für Textiltechnik der RWTH Aachen University, n.d.), www.life-insushell.de/en/downloads.html. The term has been used about concrete reinforcement since 1999 at the "Collaborative Research Center 532" based at RWTH Aachen University; see for example summary of a prototype building project (2006-2010)

of flexibility. Thus the textile can be viewed as 'concretized', and the concrete as 'textilized'.[20]

If the potential of this shell is its composite textile-concrete nature, could Concrete Canvas,[21] a specific textile-concrete product, then be used to simplify the process? The interior textile inside acts as fiber reinforcement, and the surface as a flexible forming textile, as the canvas is draped or pulled and supported in a dry condition and then simply 'watered'. Certain aspects of this method can be compared with the construction method for Nervi's ferrocement elements, where the Italian researcher Tullia Iori described how iron mats formed over a mold are 'baptized' in thin mortar.[22] Nervi brings a new line of questioning with regard to the scale and function of the forming method, rational procedures of construction, and the role of the maker. The study of the roles of the textile in the experiment also points to a division of interests in the general development of fabric formwork for architectural constructions. This development of structural textile surfaces can thus be divided into a study of their concrete futures, a study of their textile futures, and the development of an explorative sculptural practice of making.

METHODOLOGY - NATURAL AND MANIPULATED FORM

Does the experimental case relate to West's hypothesis of constructing direct fabric-formed molds of structural shapes with the practice of form-finding by means of hanging membranes?

Heinz Isler was interested in finding simple and efficient structural forms and used membranes to pursue this ambition before construction the full-scale structures in rigid formwork. West acknowledges a resemblance in the methodology for the form-finding, but since West does not consider the constructability of his thin concrete shells at really large scales, the aspect of scale as well as context are absent from the work.

The main difference between Isler's hanging-sheets models and the *Fabric-Formed Rigid Mold* has to do with the role of the manipulation of the textile. Isler's models only define simple points in the boundary condition and the overall slack of the textiles; the rest is left to the natural deflection of the material under the uniform weight of the material itself.[23]

The analytical case accomplishes the initial formal principle by manipulating the textile to achieve corrugated forms.

By adding weight from a uniform layer of concrete, the textile intensifies the initially occurring corrugation. West describes the forms of the rigid molds as *"given to us by the natural deformations of these simple flat-sheets [of fabric], and [they] are, in this sense, "found", "natural", structures."*[24]

The quotation marks around *found* and *natural* indicate the distinction from Isler's method of natural form-finding. The method of *"finding form"* at CAST, derives from a practice of drawing.

> *"These graphite drawings, sometimes made on top of photo-collages, and sometimes made on white paper, follow original techniques of discovery and invention where form and space are found rather than strictly 'composed'."*[25]

A similar practice is expressed and can be found in the work with models and prototypes. The difference from the virtually constructed and imagined places in the drawing lies in the structural physical realm of prototypes.

20 Mark Garcia, "Introduction, Architecture + Textile = Architextiles," in Architextiles, vol. 76 (London, England: Wiley Academy, 2006), 7. The book is introduced by the juxtaposition of the increasing 'architecturalization' of textiles and 'textilization' of architecture. The 'concretization' of textiles can be related to the increasing architecturalization of textiles as framed in the examples of the Practical Investigation chapter.

21 Concrete Canvas is manufactured as the impregnation of a custom-made cement blend with various admixtures into a 3D synthetic fiber matrix with a PVC coating. The nominal weights of three types of concrete-impregnated fabric are 7kg/sqm, 12kg/sqm and 19kg/sqm. In the FAQ section, see Concrete Canvas, "Rapidly Deployable Infrastructure", Company, n.d., http://www.concretecanvas.co.uk/ (Accessed 11-10-2011). See also the chapter Textiles in Construction.

22 Iori, *Pier Luigi Nervi*, 23. The Italian researcher Tullia Iori describes the process 'baptism' and compare the process to Nervi's ferrocement in which iron mats are 'watered' with thin mortar.

23 For example fabric and resin or freezing water.

24 West, "Thin Shell Concrete From Fabric Molds", 2.

25 "CAST :: Mark West Drawings", u.d., http://www.umanitoba.ca/cast_building/people/mark_drawings_gallery.html.(Accessed 15-12-2011)

Manipulation and 'drawing'

The stereogeneous reading of the shell brings elements of "made" form and West's understanding of "found" and "natural" form together. The controlled and specific pull action and the construction of the rig are thus key factors for the resulting form.

The first set of casting procedures in the Fabric-Formed Rigid Mold case is concrete form-*making* as a result of the material dialogue between textile and concrete; it reflects the flexible character of the fabric and its manipulation by the maker. The level of manipulation is primarily controlled by the specific pull action and the design of the rig: The tensioned fabric is pulled between specific points, and the rig defines the edge conditions that apply to the form. A metal pole in the rig forms the 'spine' in the middle of the shell. An arched spine would have produced increased tension and enhanced the bending-moment-shape of the shell.

Levels of manipulation are also present in the selection of textile properties and in the procedures of concreting when a thin layer of concrete is applied to the fabric little by little. The level of 'self-organization' in the fabric varies, depending on the elasticity and tautness of the given fabric and the weight of the applied concrete.

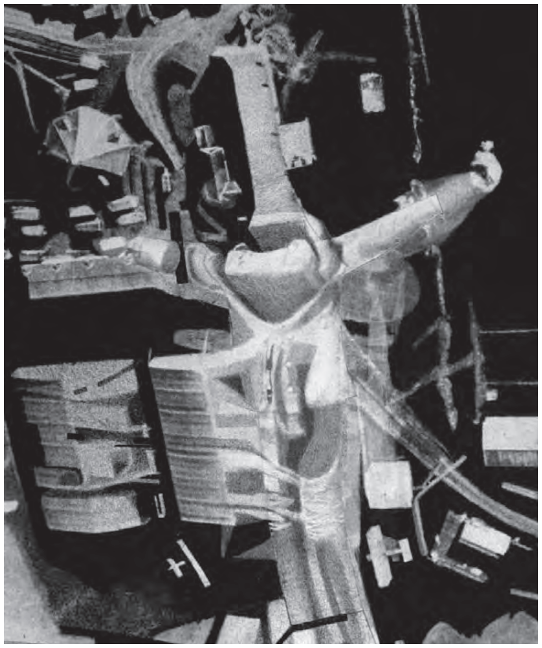
In connection with the 'concretization' of the specific textile and the 'textilization' of the concrete shell, it can be argued that the structural sculptural shape is the result of the maker's interest in capturing the structural behavior of textile and has less to do with an interest in concrete. The shell can thus be understood as rigidized textile. In relation to the future potentials of rigid textile structures, fabric forming may be moving toward a change in casting material? There is no need for the rigid wrinkle to be made of concrete – so why not find another suitable material for rigidizing the textile?

What would happen if a stretchier textile were used, along with a much lighter casting material? Would the buckles be similar, or would the surface be smoother? This interest in textile form marks a return to the interest in structural shapes resulting from a manipulation of inherent textile properties. In the earliest fabric-formed concrete shells that were created around the time of WWII, concrete was used to form 'textile' shelters. These corrugated shells indicated a simple way of building efficient structural shapes on site.

Fabric as formwork is used to enhance a *concrete* performance or behavior by *shaping* the concrete. The *Fabric-Formed Rigid Mold* displays a series of architectural investigations of the rigidization of shapes based on *textile* behavior. The development of corrugated shell forms that 'freeze' textile wrinkles can be seen as sculptural and structural explorations and, to a large degree, as an exploration of making.

On form-eruption research practices

In his essay "Arrival of Form,"[26] Mark West describes the general material research practice at CAST in the introduction to his so-called form-eruption drawings, where the drawing medium, graphite, springs from hallucinatory origins.[27] Despite the advanced use of material technologies and techniques in this experimental case, it is important to bear in mind that the experimental and playful research practice and West's 'form-eruption' practice of drawing and model making are driven by the same incentive of dreaming possible futures into being through making. The following quote by West offers insight into the intuitive practice of graphite drawing by a skilled artist. The description of the eruption of virtual forms also offers insights into the changing conditions of textiles and concrete in the 'form-eruption' practice of 'drawing' the *Fabric-Formed Rigid Mold.*



'Black out' Graphite drawing by Mark West (Illustration in 'Arrival of Form')

26 West, "The Arrival of Form"

27 Ibid., 5.

"As the image one sees is gently clarified, it is simultaneously and necessarily altered into its next mutation, obscuring the very image being clarified and resolving into a new image according to its own altered terms. This new emerging image is itself clarified/altered, in a fluid game of an image chasing itself, destroying itself, to find an emerging new self. [...] [T]he final image both contains and obscures the many previous forms and images that constitute the morphogenesis of the picture. They are 'in there', yet no longer visible as themselves. The author of such a drawing – if we can use that word for someone who is only following what is already given to sight – holds a secret knowledge of the drawing's inside story."[28]

The emerging image described by West can be compared to the emerging structural forms previously discussed. The role of the author of the drawing and the fabric-formed shell can also be compared. Even if no one would argue that the graphite image in reality simply has appeared, without a maker, but the artistic practice is represented as hallucinatory, and in that sense, the maker can be seen as being in unison with the drawing. Similarly, preparations for the *Fabric-Formed Rigid Mold* is comparable to setting the stage and tuning the selected instruments in preparation for a performance by skilled musicians.

The built work may be a sketch, similar to a chalk drawing or a computer rendering. The difference lies in the static consequences of the various modes of drawing. The hand-drawn sketches can be reworked and refined during a conversation, but since the cast has boundaries (the rig and the tensioned textile), the first act of material dialogue in concreting research takes place during concreting.[29]

Conclusion

Fabric-Formed Rigid Mold explores the use of *pull-buckles* in textiles as the structural feature of the concrete shell. In this sense, a specific textile notion is translated into concrete. The analysis of the role of the textile in the two sets of casting procedures in the experiments points to a material transformation, specifically, a transformation in the role of the textile in the procedures that translate the textile notion to a concrete structure.

The study of the technological role of the textiles in the experimental data has shown that these textile categories allow for broad understandings of their properties and potential technological roles in concrete construction.

The *Fabric-Formed Rigid Mold* is reinforced with a glass fiber net that contains textile properties; this offers a simple way of reinforcing the doubly curved surfaces of the shell. Despite the descriptive name 'textile concrete,' textile technologies used to produce reinforcement nets for concrete have not yet found actual applications that enhance the textile properties.

The overlapping properties of a 'textilized' concrete and a 'concretized' textile in the case points to the potential for the development of the composite textile to consist of a thicker reinforcement layer, which would further serve to simplify the procedures.

28 Ibid., 3

SYMBOLIC AND TECHNICAL POTENTIALS OF THE TEXTILE

Roles of the textile

Tension and suspension of a material research field

Surface as structure

ROLES OF THE TEXTILE

The dual-sided technological role of the formwork element textile was the subject of the analytical studies of the *Ambiguous Chair*, the *Fabric-formed Rigid Mold*, and the *Composite Column*.

The analytical studies focused on experimental data that explored different principles for the use of textile as surface. The three main findings in the studies of textile as surface are the potentials of the textile formwork *embraced*, the *embracing* textile, and the *rigidized textile wrinkle* structures.

The textiles used in the studies point to the manufacture of textiles as a combination of material properties and procedures.

Discussions of the textile potentials vary between structural and rhetorical form-giving roles. Hence, a next obvious step would be to scale up some of the findings of the textile notions and principles. The labeling of these textile roles are based on the observations and interpretations of experimental data – in this way, the vocabulary is arguably objectively formulated. *Textile as structure* enters the discursive or associative theoretical application of the potentiality of this textile vocabulary. A discussion of the potentials of these structural roles of the construction of the textile itself follows as a natural extension of the experimental studies of the structural roles of sheets of textile It is important to distinguish between textiles that simply result in a characteristic *concrete surface* and the *concrete forms and structures* that are the result of these textile roles.

Scope of the chapter

The chapter is divided into overlapping categories, including a summary of the characteristic properties of different textiles used in the experimental data and their qualities or potentials for concrete applications. Other categories are S*urface as Structure* and *Concrete Surfaces*. *Tension and Suspension* is a chapter within this chapter, so to speak. It frames the work at CAST to suggest that a historical and topical loop is made within the architectural investigations of fabric formwork.

Summary of textile properties

Of all the experiments included here, the *Fabric-formed rigid mold* has displayed the most advanced technical applications of textiles as formwork and the most 'textile' use of textile reinforcement. This points to a) the potentials of the different categories of textiles that are used in the experiment and, more importantly, their properties, and to b) a line of potentials that follow the construing and construction of textile formwork principles and concreting investigations that this experiment belongs to.

Composite textiles

The general potentials of *composite textiles* point towards a large spectrum of options that come from creating hybrid materials with a variety of properties. This subject will not be explored further here; I refer the interested reader to the studies of the specific properties listed above for the textiles used for the *Fabric-Formed Rigid Mold* and the properties of the wood-textile composite used for the *Seal* and the *Composite Column*.

The rhetorical and technical roles of the double-layered formwork for *Chalmers Column* and the embracing net for *Net Wall* categorize these formwork textiles as composite. For applications on larger scales or in larger numbers, the potentials of all these systems can be explored in the industrialized manufacture of textiles with desirable or appropriate properties.

The composite textiles in the experiments show potentials for the prefabrication of lightweight specialized formwork materials. The behavior and properties of these composite textiles vary and display potentials with regard to concreting procedures, structural and sculptural form, and different concrete surfaces.

In regard to the use of composite textiles as formwork element, it is important to understand their different technological roles. In the Fabric-Formed Rigid Mold the role of the composite formwork textile displays a potential for the prefabrication process of identical concrete elements and appears related to other fiber reinforced composites, such as glass fiber molds. For the *Seal*, the design of the composite textile shows potentials for unique, facetted textile surfaces based on a simple manufacturing technique. For columns, the potential of the composite textile relates to their overlapping roles of sculptural forming and structural embracing.

TENSION AND SUSPENSION OF A MATERIAL RESEARCH FIELD

Mark West has explored the notions of tension and suspension[4] in their literal, technical sense by suspending textiles in a structural frame. This condition of the preliminary procedures of form-making and construction of concrete shells represents textile used as an architectural tool that dates back to the earliest human settlements, and which in this sense parallels Semper's definition of the textile as the creation of architectural space and the separation of structure and space.

The condition of later procedures of the *Fabric-Formed Rigid Mold* represents architecture as described by the Italian architect-engineer Pier Luigi Nervi: "*Rather than technology as well as art, architecture is and must be a 'synthesis of technology and art*'."[5] This is made explicit through the concreting procedure that fixes the tensile structure and makes it structurally independent from the frame. West recombines these structural and space-defining architectural elements and refers directly to the experimental form-finding work of Heinz Isler.

West argues that the novelty of this reinvention deals with the direct application of form-finding procedures and materials to the full scale of construction.[6] In a critique of this argument, one may point to the differences in the size of the 'full scale' of these structures. Isler had to translate form-finding into the construction of large-spanning structures on the scale of buildings. The scale of West's large prototype is the size of small-scale building components, which makes comparison to the earlier work by Eladio Dieste more applicable and no less interesting.

Curtain wall

West has produced suggestive charcoal drawings of 'draped concrete-sprayed textiles' as facades for building structures, which he jokingly referred to as curtain walls.[7] This pun on the metaphor for the applied building skin as a textile decoration/structure suspended in a structural system may remain just a curiosity for a few projects or two if the hung fabric-formed concrete elements are not articulated further.

4 In the dual-sided meaning defined by the Danish word *udspænde*. According to the dictionary www.ordnet.dk, the Danish verb *udspænde* means to tension, suspend, and even to inflate. Technically it is used to describe the spatial and technical act of setting up a tensile structure or spreading a net for fishing. Rhetorically it is used to define the mental construct of a concept. In the Book of Isaiah 40:22 it used as a poetic, biblical metaphor in which the heavens are 'stretched' like a canopy. In Danish '*udspændt som et telt*' to live in. This is an example that applies the notion of suspension with a play on the multi-sided meaning of the Danish word for Heavens, *himmel* that also refers to the sky as we see it, and the canopy as a structural and spatial type. This translation of a technical procedure into a conceptual notion of space is a metaphor of literally suspending a sheet in order to define a conceptual space. For example a canopy bed - *Himmelseng*. For the discussion of fabrics used as formwork, the word *om-spænde* ('suspend around') may thus call for a similarly loaded English word than the English word embracing that is used in this dissertation.

5 Nervi, *Aesthetics and Technology*. From the preface.

6 West, "Thin Shell Fabric Molds."

7 In lectures, fx at Concrete Flesh workshop, November 2009, Chalmers University, Göteborg, Sweden.

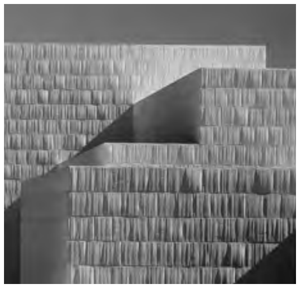
The concept of wrapping objects and constructions has been elaborated in temporary artistic installations by the duo artist-couple Christo and Jeanne Claude.[8] Looking beyond their strong artistic notion of revealing through concealing,[9] the actual wrapping structures appear similar to permanent architectural applications such as the façade for a Civic Center in Sevilla (2000) by Miguel Fisac. (Fig. 1-2)

Fisac is interesting in this discussion, because his work displays an interest in the use of concrete aimed at exploring the formal-sculptural potentials of the material, as in the cultural building, as well as its formal-structural potentials, as developed in the patented concept of the 'bone beam'.[10]

Sculptural work by Miguel Fisac, Mark West and Andrew Kudless[11] represent the formal-sculptural possibilities in the material dialogue when casting in responsive membranes. The more subtle stereogeneous presence of poured matter in the cultural center (2000) suggests a more textile expression. This wrinkled textile is used as cladding and it literally wraps a building, it holds an architectural potential that can be explored in endless combinations with the textiles used for the Fabric-Formed Rigid Mold.

When this application is used to construct thin structural compression shells, the work can be described as formal-structural. If the application of construing and constructing textile buckles that are concreted into thin concrete shells is used for thin façade panels the procedure could still be described as formal-structural. The significance of the construction process, however, will have shifted toward the formal-sculptural as it shifts from 'structural art' to a Semperian *Bekleidung* hung upon a load-bearing structure.

1



2

Left, image of bridge wrapped in textiles, Pont Neuf, Paris (1985), Christo and Jeanne Claude. Right, flexible formwork used for Cultural Center, 2000, Miguel Fisac. (Reprod. from AV 101)

3

Concrete canopy cast in a plaster mold. Teacher Training Center, Madrid (1954-57) Miguel Fisac

Evolutionary loop

A return to Waller's fabric-formed Ctesiphon principle, introduced in the Fabric Formwork chapter, and Fisac's earliest use of concrete can help define a loop in material interest within the architectural investigations of fabric formwork.

For the Teacher Training Center in Madrid (1954-57), Fisac initiated work that would lead to the patent for flexible formwork.[12] Fisac constructed long and thin, sinus-shaped concrete canopies made in a mold of plaster and rope, shown in figure 3.[13] These studies in formal-structural lightness were later exchanged with the search for an expression of liquid origins. The heavy, bulging stereogeneous presence of the façade elements in Fisac's late work is achieved from concrete pours and results in heavy elements. Mark West achieves the same stereogeneous presence in his early sculptural work by using elastic textiles. The elastic textiles appear to have the role of enhancing the plastic expression of concrete. Recent structural experiments at CAST show the opposite interest. Thin layers of concrete are applied to textile in order to enhance textile wrinkling.

The shifts in the practice of Miguel Fisac and Mark West form a loop from the exploration of thin structural form; to the study of concrete expression or sculptural form; and onwards to an interest in the expression of the self-organization of a manipulated textile. The latter marks a formal return to Fisac's Sinus-shaped canopy, which has briefly touched upon the simple construction principles of Waller. An important difference is West's use of contemporary textile manufacturing techniques and concrete types are new thus raising the bar for entering into the next round of this evolutionary loop of development. (fig 4)

8 Christo is Bulgarian, born 1935. Jeanne Claude was French-Morrocan (1935-2009)

9 "Christo and Jeanne-Claude," Artist Homepage, *Christo and Jeanne-Claude*, n.d., www.christojeanneclaude.net. "While the intricate details of the structures are hidden, the essence of the structures are revealed all the while making the imposing and solid structure seem airy and nomadic." From the FAQ section of the website.

10 Their hollow structure would span long, and they offered insulation against the hot Spanish sun. The section was designed to reflect the rays of the sun and allow indirect sunlight into the buildings. The sections of the beams also acted as an ornamental border on the facade of for Center for Hydrographic Studies, Miguel Fisac, 1960-63

11 As introduced in the Scope of Investigation

12 Fernández-Galiano, *Miguel Fisac*, 40–43.

13 Ibid., 43.

14 "Gaudí's Hanging Presence" IN Prof. Neil Leach, David Turnbull, and Chris Williams, eds., *Digital Tectonics*, 1st ed. (Academy Press, 2004). Since Antoni Gaudí's death in 1926, various architects have continued the project of maintaining the ideas of Gaudí and building La Sagrada Familia (Barcelona, Catalonia, Spain (1882-).

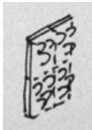
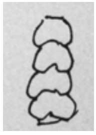
Focus	construction	formal-structural expression	material expression	material expression	construction + formal-structural expression
Principle	 Ctesiphon principle, rendered suspended fabric	 Canopy cast on rigid plaster mold	 Panels cast in flexible formwork	 Fabric-formed sculptures	 Thin-shells cast in fabric-formed rigid mold
Author	Waller	Fisac	Fisac	West	West/CAST

Fig 4, Table of the evolution of focus of fabric-forming for fabric-formwork from Waller and Fisac to West and CAST

SURFACE AS STRUCTURE

The duality of the applications, for structure or form, of the Fabric-Formed Rigid Mold calls for a comparison to the Catalan architect Antoni Gaudí (1852-1926), who brought the use of the catenary principles to fame. The catenary principles aided structural investigations in his hanging chain-models, and form-optimizing mathematical principles are seen in the development of columns of La Sagrada Família.[14] A similar formal language, typical of Art Nouveau at the time, is, however, applied in the interiors and furniture designed for projects such as the remodeling of Casa Batlló,[15] where a notion of softness and naturalness is present inside the building, while the exterior walls appear as if they were made of leather.[16] The construction of the thin, double-curved and perforated balustrades for the balconies on the façade of Casa Batlló is a suggestion of one direct application in which the strength of fiber-reinforced concrete, the pliability of responsive formworks and the repeatability of construction in fabric-formed rigid molds could fulfill both structural and formal potentials. (fig. 5)

Fig. 5. Balconies on the facade of Casa Batlló, Barcelona. (AMM)

Structural potentials of push-wrinkles

The *Fabric-Formed Rigid Mold* experiment is an investigation of the structural potentials of textile pull-buckles. The textile tension, from the manipulation of pulling and the application of concrete, causes a deflection, as the material self-organizes into an approximate minimal surface between the rigid edges. These 'pulled' rigidized wrinkles form a linear, structural corrugation, and thus, the structure resembles and 'works' like a beam.[17]

Architectural potentials of self-organization in *push*-wrinkles may contain more radical structural potentials for textiles than the *pull*-wrinkles. *Pushing* textiles on a flat surface also results in self-organization that appears accidental and chaotic. Instead of achieving structures that resemble well-known linear elements, the real potential of the pushed wrinkles may be to display a material behavior that is uniform in all directions. Such forms are otherwise difficult to develop in the tradition of Euclidean geometry.

The late Danish structural engineer Jørgen Nielsen, professor at RDAFASA, suggested a

15 In Barcelona, Spain. built by Antoni Gaudí between 1904 and 1906, commissioned by the textile industrialist Josep Batlló. I first published this comparison in a blog-post in October 2009 http://concretely.blogspot.com/2009/10/one-gaudi-beam-and-fabric-formed-shells.html (accessed 2011-10-09).

16 Zerbst, Rainer (1997) "Antoni Gaudí – the Complete Buildings," Taschen, Cologne, Germany, p. 162.

17 As explained by structural engineer Ole Vanggaard, professor at RDAFASA. The following arguments are based on a series of consultations in November and December 2011.

theory for folded plates in which the lines of force do not need to be continuous to achieve structural unity.[18] In practice, such forms would be difficult to calculate, but it is possible to study them in empirical studies. The 'chaotic' character of the form-finding method of pushing is likely to enable playful structural solutions.

The architectural scholars Mohsen Mostafavi and David Leatherbarrow assert that *"finishing ends construction, weathering constructs finishes"*.[19] Incorporating the concrete surface as part of a stereogeneous thinking includes the future life and 'aesthetic decay' or weathering in the design of architectural surfaces.The manufacture of specific formwork textiles could provide the basis for a weathering pattern and thus combine rhetorical and technical aspects of a textile concrete surface as architectural potential designed to mature and come to life over time.

The images on this page show surface reliefs and weathered rock (Fig. 6). Mosses inhabit engravings in tombstones that have been subject to weathering over centuries. A similar subtle 'invitation for inhabitation' is achieveable in concrete and future studies in fabric-formed concrete surfaces will likely reveal new methods.

6 Surface reliefs and weathering on tombstones in Trondheim, Norway. Mosses inhabit traces of engravings. (AMM)

18 Ibid.

19 Mohsen Mostafavi and David Leatherbarrow, *On Weathering: The Life of Buildings in Time* (The MIT Press, 1993), 5.

5/ PERSPECTIVES

Perspectives

Reflections on the Industrial PhD

Language, writing, methodology

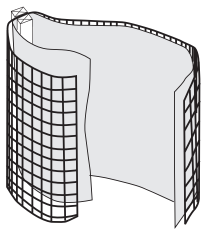
Contribution to practice

PERSPECTIVES

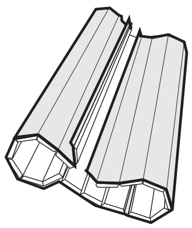
Revisiting the hypotheses and research questions

This final chapter will revisit the main research themes and summarize findings in regard to hypotheses and research questions concerning materials, principles, and the architectural expression of construction of fabric-formed concrete.

MATERIALS AND PRINCIPLES OF CONSTRUCTION



Embraced textile/ composite formwork



Embracing textile/ composite formwork

The overlapping themes relate to the technological transfer of textile notions and principles to the construing and construction of concrete structures.
Here, a hypothesis of the dissertation proposed *that a range of potentials are present in dual-sided textile roles in fabric in the construing and construction of fabric formed concrete structures, and that architectural potentials of fabric formwork lie in the understanding achieved through the localization and formulation of textile categories and textile roles.*

What are the architectural potentials for fabric formwork for concrete structures with regard to the materials, the principles, and the architectural expression of construction?

The main problem framed in the industrial context describes the dichotomy between formal ambitions and the pragmatic problem of buildability in construction.

Of the seven analytical cases, two are found to be especially interesting, the *Net Wall* and the *Composite Column*.

They are both experiments, which investigate the relation between form-giving and structural roles of fabric formwork. Their focuses overlap, as they are both of a composite nature divided into the formwork element that gives form and that which contains concrete. The Net Wall was investigated through of the role of the form tie in lack of a better focus. The tie was in fact connected with a form-giving net, a Semperian 'system of knots' that contains flexible properties similar to a textile, but can be made rigid as a sandwich construction.

The Composite Column was the prototype of a simple formwork system, which only consists of a prefabricated composite textile that, in the incorporation of wooden formwork planks, has embedded form- and surface-giving properties as well as bracing elements.

A special aspect for both construction principles is the potential of scale as well as customization, that is to say, the textile embracing net can be produced in multiple varieties of netting, and the same for the composite wood textile, which in the prototype applied conventional formwork boards.

These principles have also received attention at the contractor. Colleagues working on an Off Shore, underwater project in Sri Lanka contacted me for a dialogue about the application of the embracing net principle. And, based on a simple step-by-step communication of the construction principle for the Composite Column, the simple was found so simple to grasp that office staff in the communication department was inspired to suggest colleagues via the intranet to make a column at home…

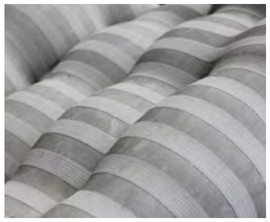
The two examples show how textile principles in two different ways can impact principles of construction as well as the expression of construction on concrete form and surfaces. The *Composite Column*, however, appears as a facetted concrete structure poured in a wooden form and thus hides its textile as a backing. In this regard, the dissertation suggests new technical roles textiles to produce irregular geometries with simple means.

Concrete **Textile**

Optimization of concrete typology

Textile as formal-structural surface

Construction as ornament
Expression of elements of construction



Formwork surface as decoration

Classification of principles, materials, and architectural expression of construction from the analytical investigations.

ARCHITECTURAL EXPRESSION OF CONSTRUCTION

Research question:

How do new principles for the construction of fabric-formed concrete, when leaving traces of its making, inform the architectural vocabulary of concrete
- and how may the expressed principles and procedures of construction inform the understanding and use of concrete as material and process?

The dissertation concludes that architectural potentials as well as challenges for the construing of fabric formed-concrete are closely related to its construction. Here the 'Handful'-model led to a specific formwork-tectonic approach. This approach can be summarized as a careful study of individual structural formwork elements and their relation to the structural formwork principle and the stereogeneous consequence. In other words, the relation between parts and whole. Design focus based on Frame, Form Tie, or Textile can thus fulfil potentials. As findings in this dissertation propose, construing and construction of fabric formwork focusing on overlapping roles of formwork elements become more complex and less categorizable. It is however here, that the most novel architectural potentials can be found. To return to Frampton's definition tectonic form as 'poesis ' of techné is brought forth or revealed, this is where concrete can be described as poetic.

The research question lead to the related concepts of formwork tectonics and stereogeneity. The former describe the relation between materials and principles of formwork construction, and the latter describes the relation between the expressed manifestation of principles and procedures of construction. Both concepts can be applied for other types of formwork but they have been found to be especially valuable to discuss the quality of fabric-formed concrete.

The direct stereogeneous consequence from the formwork-tectonic principle demands that careful attention is made to all aspects of construction. The reason is that the potentials also form the basis for the challenge for the implementation of the formwork method. Miscommunication and inaccurate preparations during the workshop Three Columns at RDAFASA caused the formwork and thus the column to sag as the concrete and formwork found its equilibrium. This makes the formwork method very fragile for in situ construction. This conclusion is emphasized by the fact that fabric-formed concrete is fragile during the curing stages. In conventional rigid formwork construction, the sturdy formwork supports and protects the concrete until it can support itself. For fabric-formed concrete, the concrete is only supported and not protected from exterior factors on the construction site. The traces of construction are thus a formal potential as well as a challenge for the implementation in large-scale construction, especially for in situ cast construction. This indicates that fabric formwork should

Left table, deggrees of prefabrication in construction in the thesis work in terms of prefabricated formwork and prefabricated concrete elements

	Pour off site	**Pour in situ**	**Pour on site as element**
Construction of formwork off site	Prefabricated concrete elements	Prefabricated formwork	Prefabricated formwork, serial production on site
Construction of formwork on site		Traditional construction	Custom made elements / serial production

find application in prefabrication of concrete elements that can still be very expressive of their becoming.

It has been an interest of the author, since the work with Flydende Sten, to discuss ways to achieve architectural qualities associated with in situ cast concrete. combined with the aim to produce large concrete elements to challenge the formwork through high formwork pressure and the lack of workshop facilities this resulted in the production of concrete structures produced on site. The methodology of the thesis work was based on on site construction, or at least the in situ pours of prefabricated formwork structures. TEK1 2010 involved predominantly in situ casting, that is to say, the concrete walls and Composite Column were cast upright and left standing. For the remaining workshops and experiments the concreting method varied between vertical pours and poured objects, which was later turned, i.e. the *Seal* 2009, the *Ambiguous Chair*, two of four objects cast at Erasmus Concretum Workshop and most of the benches at TEK1 2011.

A rigid dichotomy between prefabrication and on site casting understood by the author has proved too rigid for fabric formwork. Disregarding aspects of scale, the experimental data thus contribute with two categories of a series of relations between formwork and concrete in construction as illustrated in the table above.

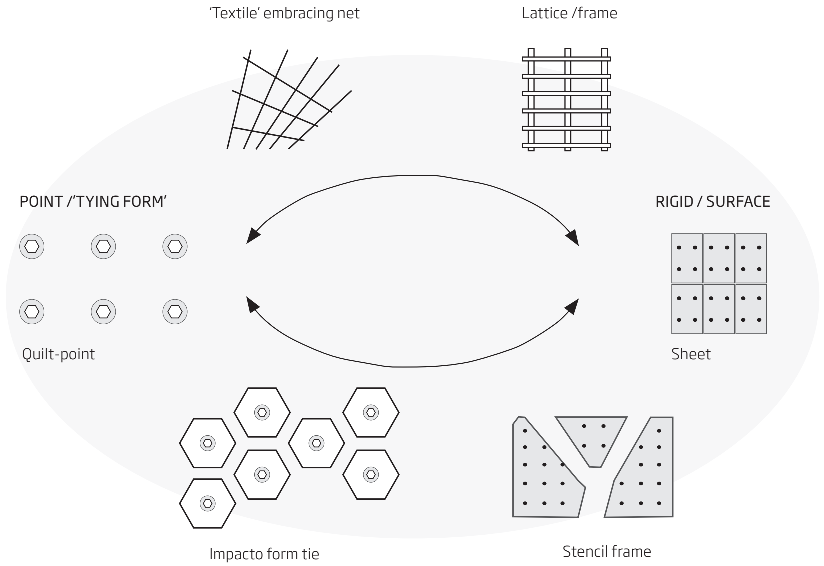
Hypothesis:

When traditional construction elements, the frame and the form tie, are expressed in the cured concrete structure, particular aspects of making are expressed in construction. This will lead to new rhetorical and technical roles of formwork elements for concrete.

The hypothesis was addressed in the analytical investigations of the frame and the form tie and research questions.
The dissertation has coined or elaborated a number of terms to describe new details of formwork construction. The circular model of degrees of restraint, relaxation, and form-tying principle was developed in the analytical investigations.

The embracing net is seen as a Semperian system of knots (points); this system is further rigidized when represented as the lattice/frame.

One can conceive the form tie as originating from the knot and depicted as the quilt-point.



The difference between the understanding of the impacto and the stencil frame is that the impacto represents an addition of a 'rigid surface' to the point, while the stencil frame represents a removal of surface from the rigid sheet.

A few formwork details are:

- The form tie already contains the terms quilt-point and Impactos. The latter was describes as a particular maker's mark – expressing a presence of construction
- Rigid seams are clamps and braces in fabric formwork, details with technical and decorative potentials
- The Stencil frame was located in the study of the *Form-Efficient Beam*. The naming of the principle of a formwork element is a contribution to the architectural vocabulary for fabric formwork and is the mirror-element of the stamp-like impacto.

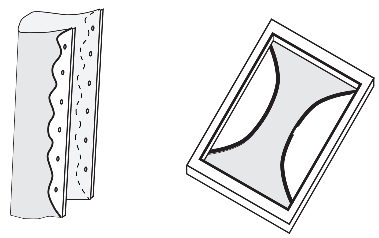
Above: The figure displays degrees of restraint, relaxation, and form-tying principles.

REFLECTION OF THE INDUSTRIAL PHD

Commercial implementation

Hypothesis in regard to strategic use of formwork tectonics:
New roles of traditional elements of construction act as 'common denominators' of artistic and practical significance and lead to implementation in contemporary construction.

This hypothesis is still open. During the thesis work, details as common denominators have been a theme of investigation. Since the project did not happen to be tested in industrial practice, the practical hypothesis has not been tested.



Rigid seam Stencil frame

The seam is a detail of construction named in the dissertation

I would have liked to discuss the implementation of fabric formwork in contemporary practice of construction as well as the development of possible new markets and in this regard address commercial aspects and strategies of innovation. This is highly relevant in the context of the Industrial PhD programme and was the subject of the report I made for the mandatory business course.[1] The report discussed availability and accessibility, image and tradition as four important points for the commercialization of fabric formwork. Here, commercialization indicates that the formwork method becomes commercially viable and point to a pragmatic model of buildability between financial, technical, and architectural parameters leading to construction.[2] Availability and accessibility refer to practical aspects of obtaining knowledge of principles, and accessibility to materials and methods, where as image refer to the cultural image of concrete architecture that is very slowly changing, and tradition refer to cultural barriers for innovation in construction.

The theme has not been elaborated further in the dissertation. The task of making principles and knowledge 'available' in knowledge sharing has however been attempted with mixed success at discussed earlier. At the time of finishing the dissertation the author has taken on the task of knowledge sharing at the company again.

Another relevant topic for architectural practice and construction would be the underlying ethical discussion of appropriateness that is addressed in the work carried out at the University of Edinburgh and at CAST.

These are topics at either end of a commercial scale that have been present as underlying issues throughout the dissertation but have not been discussed further. The broad understanding of the roles of technology in fabric formwork elements developed in this dissertation was within a different scope than topics relating, respectively, to a commercial and an ethical aspect of architecture.

Challenges for the Industrial PhD Project

The project was initiated in August 2008 in the onset of the financial crisis,[3] when indications showed that the Danish market was hit, which had an immediate negative impact on the cyclical/sensitive construction sector. This had a particular effect on my collaboration with the architects, who saw numerous projects come to a halt and hence had to prioritize urgent challenges in order to maintain business stability.

At the contractor's, where the project was situated with the development department, the effect was less immediate. Lack of experience with knowledge workers in the sector and the economic recession posed challenges to my affiliation with the industrial partners.

In a (more) long-term perspective, it proved challenging for the architectural office to incorporate the knowledge of concrete technologies and innovation embedded in this project across design projects. It was also difficult to find an entry to engage in the discussion of the general and specific application of material technologies in the company. This may in part be due to the structure of this Industrial PhD project[4] and in part to the geographical challenges of working with two international companies. [5] These issues may, however, also illustrate general challenges related to the level of knowledge sharing in architectural practices: In general it is low and non-explicit in the form of tacit knowledge, possibly because "the architect has no particular training at least traditionally – in seeing the general in the specific. Rather perhaps she seeks the specific in the general."[6]

1 "Innovation i byggebranchen – udfordringer for kommercialisering af tekstilforskalling" (Innovation in the construction industry – challenges for the commercialization of fabric formwork), a 20 page report by the author based on theoretical models about innovation presented during the business course by the Danish theorist Jens Frøslev Christensen, Professor in Management of Innovation Department of Innovation and Organizational Economics Copenhagen Business School. Models included references to David J. Teece David J. Teece, "Profiting From Technological Innovation:Implications for Integration, Collaboration,Licensing and Public Policy" 15, nr. 6, Research Policy (1986): 285-305. as well as the Ten Innovation Types listed by the Doblin Group. The report was reviewed by Jacob Alsted, CEO Haslund & Alsted Consultants and Peter Holdt Christensen, associate Professor, Copenhagen Business School in October 2009

2 "Mikkel Kragh- Interviewed by Maria Hellesøe Mikkelsen" in *Material Evidence*, edited by Beim and Ramgsaard Thomsen, 66. Kragh is a structural engineer and associate partner in Arup, Milan. He was a key note speaker at the international PhD seminar 'The Role of Material Evidence in Architectural Research'.

3 "Subprime mortgage crisis," Wikipedia, n.d., http://en.wikipedia.org/wiki/Subprime_mortgage_crisis (Accessed 15-12-2011). The U.S. federal takeover of National Mortgage Associations Fannie Mae and Freddie Mac on September 7, 2008 illustrates the subprime

It has also been challenging to communicate findings, potentials and questions about the formwork method to the network of colleagues at the contractor. Questions that arose from the architectural research are displayed through images of expressive curves and 'disguised' as a cute chair; another experiment was developed.

The affiliation with the industrial PhD programme entails that practices, ambitions, and cultures of the commercial and academic partners meet and, at time, collide. CINARK and RDAFASA will benefit from an evaluation of the collaboration to acknowledge and adjust the altered role of the academic institution from the traditional academic dissertation projects; how does the potentials of experimental practice meet the industrial reality?
There is an inherent discrepancy in the methodology and the variety of 'recipients of knowledge'.

As mentioned, architects may have difficult seeing the general in the specific, and rather seeks the specific in the general. This is challenging for a project like the present in which the material evidence of the empirical work indeed is very specific. On the contractor's side, it has proved difficult to communicate the findings in a language 'they can understand'. The expressive images of experimental work have led to different assumptions. For example for the artful appearance of the ambiguous Chairs – and the simplified construction principle for the Composite Column, which was communicated so effectively, that the office staff at the communications department considered to make a column in their back yard.

It would thus be interesting to develop a workshop based model for knowledge sharing and development with industrial partners. A few attempts were made to make workshops but unclear learning objectives, and most of all the 'sacrifice' of man-hours for 'playing' appeared to be barriers for this development. During a visit to the architectural department of the Technical University of Delft, included the participation of an interesting workshop practice with a short time format, that could be worth pursuing.

Benefits from the Industrial PhD

Benefits from the direct affiliation with business partners include the day to day discussion of issues of applicability and barriers for the implementation of a flexible formwork technology with the professionals who manage an architectural practice as well as with contractors who produce concrete[7] and who are therefore generally more interested in trimming the process and the man-hours than in the enhancing architectural perspectives.

More specifically, the contractors showed less interest in what can be achieved structurally and spatially with fabric-formed concrete. Questions have focused on how fabric formwork is constructed. This has affected the analytical framework directly and supported a two-sided view on the inherent rhetoric and scientific roles of technology, i.e. logos of techné and techné of logos as introduced by the architectural theoretician Marco Frascari.

LANGUAGE, WRITING, METHODOLOGY

The dissertation has not become as fluent and reader-friendly as I had intended. Having English as a second language has been challenging. The choice of writing in English was made out of consideration for the international peers working in this field. Still, it would have been optimal to deliver a more fluid piece of writing.

mortgage crisis, which was characterized by severely reduced liquidity in the global credit markets and insolvency threats to investment banks and other institutions.

4 Dividing one's presence and energy between the three participating institutions throughout the project made it difficult to obtain and maintain an equal cultural and professional affiliation with all the institutions.

5 The main office of schmidt hammer lassen architects is in Aarhus, and the author was mainly in Copenhagen where the firm's second-largest office is located. Pihl & Søn has projects and hence offices in construction sites all over the world.

6 Kasper Sánchez Vibæk, "User Involvement as a Configurable Integrated Product Delivery," in Proceedings from MCPC2009 (presented at the Biannual International Conference on Mass Customization and Personalisation, Helsinki, Finland, 2009). The paper is based on core research projects at CINARK focused on strategies for creating architectural value in an industrialized context.

7 The term production is used by contractors at E. Pihl & Son for work in construction sites. The company's main 'production' is concrete and includes the use of prefabricated concrete elements as well as on-site casting.

The description of the initial categorization of experimental data is admittedly difficult to understand. The development in the numerous diagrams of steps in the categorization illustrate the complexity of the task of categorizing the vast amount of data- but they might not offer much deductive knowledge, which indeed is why this type of categorization was abandoned for qualitative studies of an inductive nature.

Due to technical challenges with editing the text in the lay-out program, a * is used as a reference mark in stead of numbers. Similar issues are present in inconsistent references to illustrations in the text. Especially in the analytical studies it is the hope that images and texts correspond. In other chapters, the captions should clarify the context of the images.

Experiments and teaching

The first half of the dissertation revolved around workshops and experiments of a planned as well as an unplanned character. The two planned TEK1 workshops required intense preparations and engagement throughout. The unplanned events (Scandbuild,[8] Vermont,[9] Chalmers[10]) arose as opportunities at just a few weeks' notice, and the different events all had different aims. That caused the project to remain very open-ended for a very long time. A narrower focus would have enabled a more in-depth approach. However, the deliberate choice of maintaining an open approach has also proved fruitful in ways that could not have been foreseen.

The methodology of maintaining an open and searching approach differs from a more strictly scientific and linear research approach. This type of investigation is part of the architectural education in Study Department 2 (Architecture, Town and Building), where I studied under Associate Professor Marianne Ingvartsen. Conducting a search through an investigative frame with a field of possibilities or interests rather than aiming at solving a specific problem can be a very a fruitful approach, because surprise findings can occur when the scope remains open. On the other hand, the process of grouping and interpreting ideas and experimental data can be hard to follow, precisely because it does not follow a linear course. At times, this approach is also challenging, as one attempts to navigate through the chaotic process based on a combination of 'gut feeling' and methodical rigor. Only toward the end of this undertaking have I become aware of the significance of this architectural 'upbringing,' and I now see similar features in the approaches taken by PhD students trained in other study departments at RDAFASA.

For the future research of fabric formwork, I would like to point out the inherent quality in including students, simply because the students of the workshop are future architects. All told, more than 200 students have been involved in the research for this dissertation. If the work presented here is a drop in the water of architectural research into concrete and fabric formwork, the rings have already begun to spread through the forming minds and projects of these young architects, long before the ink of the printed dissertation has dried.[11]

Another aspect that I am proud of is the mark this process has left on the RDAFASA campus. In my opinion, the studies and research that take place at an academy of arts should be allowed to take up room, even as prototypes and including the failed and ugly attempts. At the time of writing, several concrete objects from workshops as well as the three columns cast by members of CAST in 2007 are still part of the campus at Holmen. All the present work was cast on site, and since then, students and visitors have been able to look at and touch these stereogeneous objects. Hopefully, the academy will gradually become an even 'messier' place for architectural searching and finding.

8 March 31- April 2, 2009, The exhibition at the trade fair in Bella Center, Copenhagen Denmark.

9 The ISOFF workshop organized by Sandy Lawton of Arro Design, U.S., June 2009.

10 The Workshop at Chalmers University, School of Architecture, Sweden, November 2009.

11 Professor of Architectural Technology at the RDAFASA Boje Lundgaard (1943-2004) in a lecture in 1998 (during my first days as a student of architecture. The message of the charismatic professor and co-founder of Lundgaard & Tranberg Architects was essentially, 'Consider yourselves architects, not students. We are all architects, some are just more or less experienced than others.'

CONTRIBUTION TO PRACTICE

In general the dissertation contributes to the development of the field of research through design as well as study of architectural expression of constructional materials and techniques. More significantly the dissertation contributes in two ways to the knowledge and practice of fabric forming as well as by discussing the implementation of the construction method in contemporary construction. First, through the making, documentation, and comparative study of a large amount of experimental data, and secondly, by the study of the roles of specific details and principles of its making and their consequence on concrete form, surface, and construction.

The work has been carried out in a completely analogue practice, it is however the hope that the practical and theoretical contribution of the concepts of formwork tectonics and stereogeneity can be used in digital as well as analogue ways of thinking and doing concrete architecture as a series of conditions, as material and process.

BIBLIOGRAPHY & REFERENCES

Books, articles, patents, websites, and images

Abdelgader, Hakim, Mark West, and Jaroslaw Gorski. "State-of-the-Art Report on Fabric Formwork." In *ICCBT 2008*, pp 93-106. Malaysia, 2008.

Abraham, Anders. *A New Nature - 9 Architectural Conditions Between Liquid and Solid*. Copenhagen: Kunstakademiets Arkitektskoles Forlag, 2010.

Alexander, Christopher. *The Timeless Way of Building*. Oxford University Press, 1979.

Alexander, Christopher, Howard Davis, Julio Martinez, and Don Corner. *The Production of Houses*. First Edition. USA: Oxford University Press, 1985.

Anderson, Stanford, ed. *Eladio Dieste: Innovation in Structural Art*. New York: Princeton Architectural Press, 2004.

Archer, Bruce. "The Nature of Research." *Co-design, Interdisciplinary Journal of Design* (January 1995): 6-13.

Bache, Anja Margrethe. *Ny Betons Form - For Kæmpekonstruktioner*. Post-Doc. Aarhus: Aarhus School of Architecture, 2004.

Bakker, Siebe. *Concrete design book on plastic-opacity International Concrete Design Competition for Students 2006 2007*. Berlin: Bundesverband der Dt. Zementindustrie, 2007.

Beim, Anne. *Tectonic Visions in Architecture*. Copenhagen: Kunstakademiets Arkitektskoles Forlag, RDAFASA 2004.

Beim, Anne, and Mette Ramsgard Thomsen, eds. *The Role of Material Evidence in Architectural Research - Drawings, Models, Experiments*. Copenhagen: Danish Doctoral Schools of Art and Design & RDAFASA, 2012.

Bertram, Peter, and Kunstakademiets Arkitektskole. *Den animerede bygning: PhD Dissertation,* Copenhagen: RDAFASA, 2008.

Bogner, Dieter. *Friedrich Kiesler: Inside the endless house (Sonderausstellung des Historischen Museums der Stadt Wien)*. Bohlau, 1997.

Bogner, Dieter, and Peter Noeve, eds. *Frederick J. Kiesler Endless Space*. Hatje Cantz Publishers, 2001.

Braham, William W., Jonathan A. Hale, and John Stanislav Sadar, eds. *Rethinking Technology: a Reader in Architectural Theory*. Taylor & Francis, 2007.

Brameshuber, Wolfgang. *Report 36: Textile Reinforced Concrete - State-of-the-Art Report of RILEM TC 201-TRC*. RILEM Publications, 2006.

Burry, Mark, Jordi Bonet I Armengol, Jos Tomlow, and Antoni Gaudí. *Gaudí Unseen: Completing the Sagrada Família*. Jovis, 2008.

Cache, Bernard. "Digital Semper (2000)." In *Rethinking Technology: a Reader in Architectural Theory*, edited by William W. Braham, Jonathan A. Hale, and John Stanislav Sadar, 378-87. Taylor & Francis, 2007.

Chandler, Alan. "Building Walls – A Philosophy of Engagement." *Architectural Research Quarterly* 8, no. 3/4 (2004): 204-214.

Chandler, Alan, and Remo Pedreschi, eds. *Fabric Formwork*. London: RIBA Publishing, 2007.

Chard, Nat. *Drawing Indeterminate Architecture, Indeterminate Drawings of Architecture (Consequence Book Series on Fresh Architecture)*. 1st ed. Springer Vienna Architecture, 2005.

Chilton, John C. *Engineer's Contribution to Architecture: Heinz Isler*. London: Thomas Telford, 2000.

Christiansen, Karl, and Anders Gammelgaard. "Industrialiseret Individualitet", *Arkitekten*, no. 1. Teknisk tema: Systemleverancer (2006): 55-59.

Cohen, Jean-Louis, and G.M. Moeller, eds. *Liquid Stone : New Architecture in Concrete*. New York: Princeton Architectural Press, 2006.

Collectif. *L'Architecture d'Aujourd'Hui N 381*. Archipress, 2011.

Collins, Peter. *Concrete, the Vision of a New Architecture: A Study of Auguste Perret and his Precursors*. 2nd ed. McGill-Queen's University Press, 2004.

Colquhoun, Alan. "Symbolic and Literal Aspects of Technology." In *Rethinking technology: a reader in architectural theory*, edited by William W. Braham, Jonathan A. Hale, and John Stanislav Sadar, 265-269. 1962nd ed. London ;;New York: Routledge, 2007.

Conlon, Ciarán. "The Innovations and Influence of Irish Engineer James Hardress de Warenne Waller (Draft)". BA Architecture, University College Dublin, 2011.

Le Corbusier. *Towards a New Architecture*. Oxford: Butterworth Architecture, French org. 1923/ 1989.

Cornell, Elias. *Byggnadstekniken: Metoder och idéer genom tiderna*. Sweden: Byggförbundet, 1970.

Dam, H. C., L. Gerward, O. Leistiko, T. Lindemark, A. Nielsen, and O. T. Sørensen, eds. *Materialebogen*. Copenhagen: Nyt Teknisk Forlag, 2008.

DeLanda, Manuel. "Material Evolvability and Variability." In *The Architecture of Variation - Research & Design*. Thames & Hudson, 2009.

Deplazes, Andrea, ed. *Constructing Architecture - Materials Processes Structures, a Handbook*. 2 ed. Basel: Birkhäuser, 2005/2010.

Dieste, Eladio. "Architecture and Construction." In *Eladio Dieste: Innovation in Structural Art*, edited by Stanford Anderson, 182-91.New York: Princeton Architectural Press, 2004.

Dieste, Eladio. "Art, People, Technocracy." In *Eladio Dieste: Innovation in Structural Art*, edited by Stanford Anderson, 194-97.New York: Princeton Architectural Press, 2004.

Dieste, Eladio. "The Awareness of Form." In *Eladio Dieste: Innovation in Structural Art*, edited by Stanford Anderson, 192-93.New York: Princeton Architectural Press, 2004.

Drew, Philip. *Frei Otto: Form and Structure*. Boulder, Co: Westview Press, 1976.

Faber, Colin. *Candela, the Shell Builder*. Reinhold Pub. Corp., 1963.

Fernández-Galiano, Luis, ed. *Miguel Fisac*. Monographs 101. Madrid: Architectura Viva SL, 2003.

Forty, Adrian. "A Material Without a History." In *Liquid stone : new architecture in concrete*, edited by Jean-Louis Cohen and G.M. Moeller, 34-45. New York: Princeton Architectural Press, 2006.

Frampton, Kenneth. "1965-1991: Isostatic Architecture." In *Harry Seidler: Four Decades of Architecture*, edited by Philip Drew, 85-111. London: Thames and Hudson, 1992.

Frampton, Kenneth. *Labour, Work and Architecture*. London: Phaidon Press Limited, 2002.

Frampton, Kenneth. "Rappel à l'Ordre: The Case of the Tectonic." Architectural Design 3/4, 1990. In *Labour, Work and Architecture*,91-103. London: Phaidon Press Limited, 2002.

Frampton, Kenneth. *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*. Edited by John Cava. 2nd ed. Paperback. The MIT Press, 1994/2001.

Frampton, Kenneth. "Towards a Critical Regionalism - Six Points for an Architecture of Resistance." In *Postmodern Culture*, edited by Hal Foster, 16-30. Pluto Press, 1985.

Frampton, Kenneth, and Philip Drew, eds. *Harry Seidler: Four Decades of Architecture*. London: Thames and Hudson, 1992.

Frampton, Kenneth, ed. *Tadao Ando: Buildings, Projects, Writings*. New York: Rizzoli International Publications, 1984.

Frascari, Marco. *Monsters of Architecture: Anthropomorphism in Architectural Theory*. Savage, Maryland: Rowman & Littlefield Publishers, 1991.

Frascari, Marco. "The Tell-The-Tale Detail (1984)." In *Theorizing a New Agenda for Architecture: an Anthology of Architectural Theory 1965-1995*, edited by Kate Nesbitt, 500-513.New York: Princeton Architectural Press, 1996.

Frayling, Christopher. "Research in Art and Design" 1, no. 1. Royal College of Art Research Papers (1994 1993): 1-5.

Gadamer, Hans-Georg.*Truth and Method*. 2nd revised translation (from Germ.). London: Continuum, 1960/2004.

Garcia, Mark, ed. *Architextiles*. Architectural Design, Vol. 76, No. 4. Chichester: Wiley Academy, 2006.

Gast, Klaus-Peter. *Louis I. Kahn: Das Gesamtwerk: Complete Works*. Deutsche Verlags-Anstalt, 2001.

Gibson, James J. "The Theory of Affordances." In *Perceiving, Acting and Knowing*, edited by R. Shaw and J. Bransford. Hillsdale, NJ: Erlbaum, 1977.

González Blanco, Fermín. *Miguel Fisac : HuesOs Varios*. 1st ed. Madrid, Spain: Fundación COAM, 2007.se

Groat, Linda, and David Wang. *Architectural Research Methods*. New York: Wiley, 2002.

Hartoonian, Gevork. *Ontology of Construction: On Nihilism of Technology and Theories of Modern Architecture*. Cambridge: Cambridge University Press, 1994.

Heidegger, Martin. *Basic Writings : from Being and time (1927) to The task of thinking (1964)*. Rev. and expanded translation. New York: HarperCollins, 1993

Hensel, Michael. "Performance-oriented Architecture and the Spatial and Material Organisation Complex. Rethinking the Definition, Role and Performative Capacity of the Spatial and Material Boundaries of the Built Environment." *FORMakademisk Online Journal*, 2011.

Hensel, Michael, Achim Menges, Michael Weinstock, and Emergence and Design Group. *Emergence: Morphogenetic design strategies, Evolutionary strategies for design*. Chichester: Wiley Academy, 2004.

Herrmann, Wolfgang. *Gottfried Semper : in Search of Architecture*. Cambridge Mass. USA: The MIT Press, 1984.

Hodge, Brooke, Patricia Mears, and Susan Sidlauskas. *Skin + Bones: Parallel Practices in Fashion and Architecture*. London: Thames & Hudson, 2006.

Hoffman, Dan. "Consuming Vision: The Work of Mark West." *Storefront Newsletter*, New York: Storefront for Art and Architecture, September 1992.

Hopmann, Stefan. "Restrained Teaching: the Common Core of Didaktik." *European Educational Research Journal* 6, no. 2 (2007).

Hvattum, Mari. *Gottfried Semper and the Problem of Historicism*. Cambridge: Cambridge University Press, 2004.

Iori, Tullia. *Pier Luigi Nervi*. Milan: Motta Architettura, 2009.

Jensen, Casper Vibæk, and Anne Beim. *Kvalitetsmål i den Arkitektoniske Designproces*. Copenhagen: RDAFASA, CINARK 2006.

Jensen, Mette Jerl. "Revitalisering af Teglmuren". PhD-Dissertation,Copenhagen, RDAFASA, 2011.

Jones, Susan. "The Evolving Tectonics of Karl Bötticher: From Concept To Formalism." In *Tectonics Making Meaning*, 4. The Netherlands: University of Technology, Eindhoven, 2007.

Jørgensen, Thomas Ryborg. *Cinark Overblik: Arkitektur og Mass Customization*. Copenhagen: RDAFASA, Center of Industrialized Architecture, 2007.

Kahn, Louis I. "Address - 5 April 1966." In *Louis I. Kahn: Writings, Lectures, Interviews*, edited by Alessandra Latour, 208-220. New York: Rizzoli International Publications, 1991.

Kahn, Louis I., and Alessandra Latour. *Louis I. Kahn: Writings, Lectures, Interviews*. New York: Rizzoli International Publications, 1991.

Kind-Barkauskas, Friedbert, Bruno Kauhsen, Stefan Polonyi, and Jörg Brandt. *Concrete Construction Manual (Construction Manuals*. Eng. ed (from German). Basel: Birkhäuser: Edition Detail, 2002.

Kipnis, Jeffrey. *Philip Johnson: Recent Work*. John Wiley & Sons, 1996.

Klemenc, Stacey Enesey. "Decorative Concrete: Fabric Formwork" 10, no. 1. *Concrete Decor Magazine*, The Journal of Decorative Concrete, January 2010.

Kruft, Hanno-Walter. *A history of architectural theory : from Vitruvius to the present*. London: Zwemmer, 1994.

Kwinter, Sanford. *Architectures of Time: Toward a Theory of the Event in Modernist Culture*. Cambridge, Mass.: The MIT Press, 2002.

de Laet, Marianne, and Annemarie Mol. "The Zimbabwe Bush Pump: Mechanics of a Fluid Technology", no. 30. Social Studies of Science (2000): 225-63.

Lamberton, B. A. "Fabric forms for Concrete." Concrete International (December 1987): pp. 58-67.

Leach, Prof. Neil, David Turnbull, and Chris Williams, eds. *Digital Tectonics*. Chichester: Wiley-Academy, 2004.

Leatherbarrow, David, and Mohsen Mostafavi. *Surface Architecture*. Paperback. Cambridge, Mass.: The MIT Press, 2002/2005.

Leimand, Nini. "BLOKMUR - MURBLOK, det beklædte blokmurværks enkle natur og arkitektoniske potentiale". PhD-Dissertation, RDAFASA, 2008.

Lund, Morten, Sanna Nordlander, and Karl-Gunnar Olsson, eds. *Concrete Flesh - Matter Space Structure Studio Workshop November 2009*. Gothenburgh, Sweden: Chalmers University of Technology, Dep. of Architecture, 2010.

Mallgrave, Harry Francis. *An Anthology from Vitruvius to 1870*. Wiley-Blackwell, 2005.

Manelius, Anne-Mette. "Ambiguous Chairs Cast in Fabric Formed Concrete." 4. Stuttgart: CIMNE, Barcelona, 2009, 2009.

Manelius, Anne-Mette. "Fabric Explored." In *Tectonics in Building Culture: Concretum*, edited by Peter Sørensen, 25. Copenhagen: RDAFASA, Institute of Architectural Technology, 2011.

Manelius, Anne-Mette. "Fabric Formwork." In *Tectonics in Building Culture: Concretum*, edited by Peter Sørensen, 16-19. Copenhagen: RDAFASA, Institute of Architectural Technology, 2011.

Manelius, Anne-Mette. *Cinark Overblik: Flydende Sten - Betons Arkitektoniske Potentialer. Et udredningsprojekt*. København: RDAFASA, Center of Industrialised Architecture, 2007.

Manelius, Anne-Mette, and Anne Beim. "Creative Systems – Arkitektur i en nyindustriel kontekst", no. 14. *Arkitekten* (2007): 48-52.

McCarter, Robert. *Louis I Kahn*. London: Phaidon Press Limited, 2005.

McQuaid, Matilda. *Extreme Textiles: Designing for High Performance*.New York: Princeton Architectural Press, 2005.

Mies van der Rohe, Ludwig, and Peter Carter. *Mies van der Rohe at Work*. Reprint (org 1974). London: Phaidon, 1999.
Miravete, A, ed. *3-D textile reinforcements in composite materials*. Cambridge: Woodhead Publishing Limited, 1999.

Mo, Linn. *Vitenskapsfilosofi for arkitekter*. Kolofon, 2003.

Moholy-Nagy, László. *The new vision from material to architecture*, 1939.

Mostafavi, Mohsen, and David Leatherbarrow. *On Weathering: The Life of Buildings in Time*. Cambridge, Mass.: The MIT Press, 1993.

Nervi, Pier Luigi. *Aesthetics and Technology in Building – the Charles Eliot Norton Lectures, 1961-1962*. Harvard University Press, 1965.

Nesbitt, Kate, ed. *Theorizing a New Agenda for Architecture: an Anthology of Architectural Theory 1965-1995*. New York: Princeton Architectural Press, 1996.

Nordenson, Guy, and Terence Riley, eds. *Seven structural engineers: the Felix Candela lectures*. New York: The Museum of Modern Art, 2008.

Orr, John, A. P. Darby, T. J. Ibell, M. C. Evernden, and M. Otlet. "Concrete Structures Using Fabric Formwork" 89, no. 8. The international journal of the Institution of Structural Engineers (April 2011): 20-26.

Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. 2nd ed. Chichester: John Wiley & Sons, 2005.

Pallasmaa, Juhani. *The Thinking Hand*. Chichester: John Wiley & Sons, 2009.

Pallasmaa, Juhani. "Touching the World - Architecture, Hapticity and the Emancipation of the Eye." Edited by Anne Elisabeth Toft, no. 73. EAAE Bulletin News Sheet (October 2005): 34-41.

Paterson, Mark. *The Senses of Touch: Haptics, Affects and Technologies*. Oxford, UniteBerg Publishers, 2007.

Pearman, Hugh. "'Caruso St John/Cover Versions' by Hugh Pearman, The Architects' Journal, No. 21." *The Architects' Journal*, 2005.

Pedreschi, R., and D. Theodossopoulos. "The Double-Curvature Masonry Vaults of Eladio Dieste." *Proceedings of the ICE - Structures and Buildings* 160, no. 1 (January 2, 2007): 3-11.

Pedreschi, Remo. *The Engineer's contribution to contemporary architecture: Eladio Dieste*. London: Thomas Telford Ltd, 2000.

Peter, Cook. *Drawing, The Motive Force of Architecture*. Chichester: Wiley, 2008.

Petersen, Frederik. "Repræsentationens realisering". PhD-Dissertation, Aarhus School of Architecture, 2011.

Pfeifer, Günter, Antje M. Liebers, and Per Brauneck. *Exposed Concrete: Technology and Design*. 1st ed. Birkhäuser Architecture, 2005.

Prakash, Neil. "Self-Forming Masonry Compression Vaults, A Simple Method of Prefabricating Thin-Shell Masonry

Vaults Without Falsework". CAST, University of Manitoba, 2005.

Pye, David. *The Nature and Art of Workmanship*. Edited by James Pye and Elizabeth Balaam. Revised. Fox Chapel Publishing, 1968/ reprint1995.

Quinn, Bradley. *Textile Futures : Fashion, Design and Technology*. English ed. Oxford ;;New York: Berg, 2010.

Ronner, Heinz, Sharad Jhaveri, and Alessandro Vasella, eds. *Louis I. Kahn, Complete Work: 1935-74*. Special Edition. ETH, Zürich: Institute for the History and Theory of Architecture, 1977.

Sang-Hoon Lee, Daniel. "Study of Construction Methodology and Structural Behaviour of Fabric-formed Form-efficient Reinforced Concrete Beam". PhD-Dissertation, Department of Architecture, University of Edinburgh, 2011.

Sang-Hoon Lee, Daniel. "The Structural Behaviour and Construction of Form-Active Structures using Fabric Cast Concrete". Master Dissertation, Civil Engineering, The University of Edinburgh, 2005.

Schjeldahl, Peter. *Columns & Catalogues*. Great Barrington MA: The Figures, 1994.

Schmidt, Anne Marie Due. "Tectonic Practice – in the Transition From a Pre-Digital to a Digital Era". PhD-Dissertation, Department of Architecture and Design, Utzon Center, Aalborg University, 2007

Sekler, Eduard. "Structure, Construction, Tectonics." In *Structure in Art and Science*, edited by Gyorgy Kepes, 89-95. New York: George Braziller, 1965.

Semper, Gottfried. *Der Stil in Den Technischen Und Tektonischen Künsten: Bd. Die Textile Kunst Für Sich Betrachtet Und in Beziehung Zur Baukunst*. Reproduction of original. Frankfurt: Verlag für Kunst und Wissenschaft, (reprod. by Nabu Press), 1860/2010.

Semper, Gottfried. *Die Vier Elemente der Baukunst*. Vieweg, 1851.

Semper, Gottfried. "Science, Industry and Art." In *The Four Elements of Architecture and Other Writings*. Vol. 1852. Cambridge: Cambridge University Press, 2010.

Semper, Gottfried. *Style in the Technical and Tectonic Arts; or, Practical Aesthetics: A Handbook for Technicians, Artists, and Friends of the Arts*. Translated by Harry Francis Mallgrave. (org. Germ. 1860). Los Angeles: Getty Research Institute, 2004.

Semper, Gottfried. "The Four Elements of Architecture." In *The Four Elements of Architecture and Other Writings*, translated by Harry Francis Mallgrave, 74-129. (org 1851). Cambridge: Cambridge University Press, 2010.

Semper, Gottfried. *Wissenschaft, Industrie und Kunst, und andere Schriften über Architektur, Kunsthandwerk und Kunstunterricht (Open Library)*. Kupferberg, 1966. .

Sennett, Richard. *The Craftsman*. London: Penguin, 2009.

Sheil, Bob, ed. *Design Through Making*. Vol. 75. 4 vols. Wiley Academy, 2005

Soler, Francisco Arqués. *Miguel Fisac*. Madrid, Spain: Edicion Pronaos, 1996.

Spuybroek, Lars, ed. *Research & Design*: *Textile Tectonics.* Rotterdam: NAi Publishers, 2011.

Spuybroek, Lars. *Research & Design*: *The Architecture of Variation.* London: Thames & Hudson, 2009.

Strike, James. *Construction into Design: The Influence of New Methods of Construction Architectural Design, 1690-1990.* Oxford: 1991.

Stuart, Christopher, ed. *DIY Furniture: A Step-by-Step Guide*. London: Laurence King Publishers, 2011.

"Summary of Results for the Project INSUSHELL". Institut für Textiltechnik der RWTH Aachen University, n.d. http://www.life-insushell.de/en/downloads.html.

Suzumori, Shuji. "Formwork as Design Tool". Master Thesis, Architecture, Massachusetts Institute of Technology, 2006.

Sørensen, Jannie Bakkær, and Ida Højgaard Wonsild. "Vævet Geotekstil som Tekstilforskalling" (Woven Geo-textile as Fabric Formwork). Diploma project, Architectural Engineering, Technical University of Denmark, 2008.

Sørensen, Peter, ed. *Tectonics in Building Culture: Concretum*. Copenhagen: RDAFASA, Institute of Architectural Technology, 2011.

Teece, David J. "Profiting From Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy" 15, no. 6. Research Policy (1986): 285-305.

Thomsen, Mette Ramsgaard, and Toni Hicks. "To Knit a Wall, knit as matrix for composite materials for architecture." In *Smart Textiles, technology and design, International Scientific Conference, Proceedings*, 2008:9. Borås, Sweden, 2008.

Ursprung, Philip, ed. *Herzog & de Meuron: Natural History*. Springer, 2005.

Veenendaal, Diederik, and Philippe Block. "A Framework for Comparing Form Finding Methods." In *Proceedings*. London, UK, 2011.

Veenendaal, Diederik, Mark West, and Philippe Block. "History and overview of fabric formwork: using fabrics for concrete casting." *Structural Concrete* 12, no. 3 (September 1, 2011): 164-177.

Vibæk, Kasper Sánchez. "System Structures in Architecture - Constituent Elements of a Contemporary industrialised Architecture". PhD-Dissertation, The Royal Danish Academy of Fine Arts, School of Architecture, 2012.

Vitruvius, Pollo. *Vitruvius: the ten books on architecture*. Dover Publications, 1914.

West, Mark. "CAST Booklet", 2007. Center for Architectural Structures and Technology (CAST), University of Manitoba

West, Mark. "Fabric-Cast Concrete Wall Panels". CAST, University of Manitoba, 2002.

West, Mark. "Fabric-Formed Concrete Structures". CAST, University of Manitoba, 2002.

West, Mark. "Flexible Fabric Molds for Precast Trusses." *BFT International*, no. 10 (2006): 46-52.

West, Mark. "Kenzo Unno : Fabric-Formed Walls". CAST, University of Manitoba, 2007.

West, Mark. "The Arrival of Form". CAST, University of Manitoba, 2009.

West, Mark. "The Thai-Tie, a Powerful, Simple, Inexpensive Connector", 2010.

West, Mark. "Thin Shell Concrete From Fabric Molds". CAST, University of Manitoba, 2009.

West, Mark. "Thin-Shell Concrete From Fabric Molds: Technologies and Instigations from La Ciucad Abierta (the "Open City) Projecto Taller de Obras". CAST, University of Manitoba, 2007.

West, Mark, and Ronnie Araya. "Fabric Formwork for Concrete Structures and Architecture." 4. Stuttgart: CIMNE, Barcelona, 2009.

Weston, Richard. *Materials, Form and Architecture*. London: Laurence King Publishing, 2003.

Wright, Frank Lloyd. *Writings and Buildings*. Frank Lloyd Wright Foundation, 1960.

Ørskov, Willy. *Samlet : Aflæsning af objekter, Objekterne, Den åbne Skulptur*. Anthology of writings. Borgen, 1999.

Patents

Fearn, Richard. "Fabric Column and Pad Concrete Form". US Pat. 20040128922, 2004.

Fearn, Richard. "Monopour Form". U.S Pat. 20100011698, 2010

Fearn, Richard N. "Building Foundation and Floor Assembly". U.S Pat. 5224321, 1993.

Fearn, Richard N., and Herbert Walter Bentz. "Concrete Wall Forming System Using Fabric". U.S Pat. 20030168575, 2003

Herr, Richard. "Cloth Backed Plaster Reinforcing". US. Pat. 2298376 A, 1942

LIlienthal, Gustav. "Fireproof Ceiling". US Pat. 619,769, 1889

Waller, James Hardress de Warenne. "Method of Building with Cementitious Material Applied to Vegetable Fabrics". U.S. Pat. 1955716, 1934

–––. "Method of Constructing Canals and the Like". U.S. Pat. 2015771. 1935.

–––. "Method of Molding In Situ Concrete Arched Structures". U.S. Pat. 2616149, 1952.

Encyclopedias and dictionaries

The Cassell Compact Dictionary. London: Cassell, 1998.

Celanese Acetate. *Complete Textile Glossary*. 5th ed. New York: Celanese Acetate LLC, 2001.

Den Store Danske. Denmark: Gyldendal, n.d. www.denstoredanske.dk

Den Danske Ordbog. Det Danske Sprog- og Litteraturselskab, n.d. ordnet.dk

Dictionary.com
Free Merriam-Webster Dictionary", n.d., www.merriam-webster.com

Online Etymology Dictionary, Douglas Harper, www.etymonline.com

Websites are referenced in the notes of the dissertation

The most frequently cited websites are however listed below.

CAST - the Center of Architectural Structures and Technology at the University of Manitoba. This site is the source for most published references by Mark West,
"CAST", n.d. www.umanitoba.ca/faculties/architecture/cast/ (Accessed 5-02-2012).

Website of the lectures at the First International Conference on Fabric Formwork, ICFF2008, www.umanitoba.ca/faculties/architecture/cast/conference/index.html (Accessed 15-12-2011)

"ISOFF - International Society of Fabric Forming", n.d. www.fabricforming.org/. (Accessed 5-02-2012)

Manelius, Anne-Mette, "CONCRETELY." Blog, n.d. http://concretely.blogspot.com/.

Unless listed otherwise, websites in the dissertation were accessed between 15-10-2011 and 05-02-2012.

Image credits

Where known, sources are referenced (author) in the captions, which refer to the list of bibliography, except:

Nalbandyan, Mane. "Structural Analysis of Brother Claus Chapel." Blog. Mane Nalbandyan 3501, September 4, 2010. http://manenalbandyan3501.blogspot.com/2010/09/structural-analysis-of-brother-claus.html. (Accessed 25-11-2011). An analytical drawing based on a web-published photograph of a detail of the construction.

Image on the cover of this volume: detail of the *Ambiguous Chair*. Image on the cover of Experimental Data: detail of the *Clamp Wall*

Signe Ulfeldt has taken the photos in the first section: pp 3, 6, 8, 20, 28, 42; and page 238: details of formwork tectonics during and after the concrete pour at workshop 8/ TEK1 2011.

Images in the volume Experimental Data are from the student reports or by the author.

Anne-Mette Manelius
Appendix of PhD Dissertation, 2012

The Royal Danish Academy of Fine Arts
Schools of Architecture, Design, and Conservation
School of Architecture
Institute of Architectural Technology
Center for Industrialized Architecture

Manelius Experimental Data

EXPERIMENTAL DATA

Appendix of the PhD dissertation Fabric Formwork

CONTENT

1/ THREE COLUMNS AT RDAFASA 2007

2/ TEK1 2009

3/ AMBIGUOUS CHAIR 2009

4/ VERMONT WALL 2009

5/ CONCRETE FLESH 2009

6/ TEK1 2010

7/ CONCRETUM 2010

8/ TEK1 2011

9/ SELECTED TEXTS

/ CD

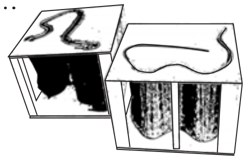
/ TABLE: DOCUMENTATION AND CATEGORIZATION

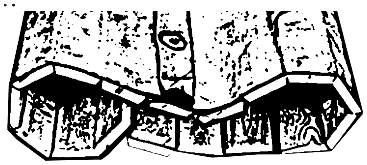
Year	Month	Participants	Experiments	Workshops and *keywords*
2007	**Sep**	<3 △	3	1 CAST at RDAFASA * *Simple means/formal consequence*
	Oct			
	Nov			
	Dec			
2008	Jan			
	Feb			
	Mar			
	Apr			
	May	△		[First International Conference on Fabric Forming (ICFF2008) at CAST, Winnipeg]
	Jun			
	Jul			
	Aug PhD Starts			
	Sep			
	Oct	△		[Visit to ESALA, Edinburgh]
	Nov			
	Dec			
2009	Jan			
	Feb	65 ▲▲	10	2 TEK1/ Sharp / soft *Flexibility / Restraint*
	Mar			
	Apr	▲	2	3 Ambiguous Chairs *Textile/Quilt point method*
	May			
	Jun	12 △	1	4 Vermont Wall ** *Quilt-point method*
	Jul			
	Aug			
	Sep			
	Oct			
	Nov	100 △▲	3^	5 Concrete Flesh *** *No restraints*
	Dec			
2010	Jan			
	Feb			
	Mar	70 ▲▲	11	6 TEK1/ Walls *Textile / Restraint/ Frame (set dimensions)*
	Apr			
	May			
	Jun			
	Jul			
	Aug	35 ▲	4	7 Concretum, Erasmus Summer School, Bornholm *Textile / Restraint/ Frame / Context*
	Sep			
	Oct			
	Nov			
	Dec			
2011	Jan			
	Feb			
	Mar	80 ▲	11	8 TEK1/ Benches *Textile / Restraint/ Frame / Context*

Analytical cases from experimental data

The *Fabric-Formed Rigid Mold* (2009) CAST

The *Form-Efficient Beam (2007-10) ESALA*



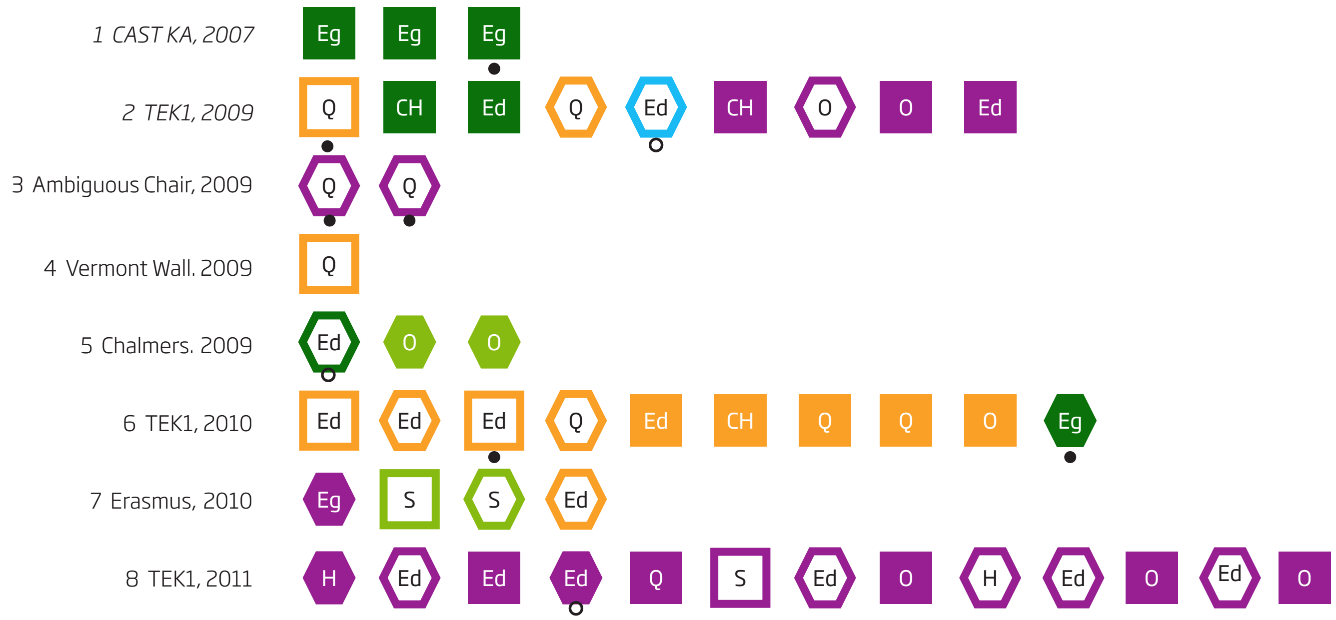


▲ 80 Workshop organizer and number of participants
△ 80 Workshop participant and number of participants
Walls
Shells, vaults
Columns, arches
Sculptural objects
5 Number of experiments
* Planned by CAST
** Planned by Sandy Lawton
*** Planned by Chalmers
^ Number of experiments by the author, not by all

SYMBOLS

CATEGORIZATION IV A

Structural formwork type - pr workshop - from section 4 in the dissertation



STRUCTURAL CONCRETE TYPE

Beam, Slab

Wall

Shell, Vault

Column, Arch

Other

ANALYTICAL CASE

Primary Analytical Case

Secondary Analytical Case

STRUCTURAL FORMWORK TEXTILE TYPE

S - Suspended

H - Hung

Eg - Embracing

Ed - Embraced

CH - Connector/Hinge

Q - Quilt points/Tied

O - Other

STRUCTURAL FORMWORK FRAMING TYPE

Rigid Back Frame Rig Other


PERI UP

1 / THREE COLUMNS AT RDAFASA

Eg Eg Eg

Workshop before the exhibition and conference 'Creative Systems'

Where: Royal Danish Academy of Fine Arts, School of Architecture (RDAFASA)
When: September 2007

THREE COLUMNS AT RDAFASA

Mark West from the Center of Architectural Structures and Technology (CAST) at the University of Manitoba was invited as a key note speaker for the conference Creative Systems in Architecture, organized by Center for Industrialized Architecture (CINARK) at the Institute of Technology.

The conference was accompanied by an exhibition, which featured work by the four keynote speakers.

The construction of three columns cast in fabric formwork was part of the exhibition of CAST's research practice. The column formwork was stripped at the end of the conference and marked the opening of the exhiibition. The aim of the workshop was to display simple methods and techniques to create advanced geometries and details in concrete structures.

Self compacting concrete was selected for the pour to test and display the use of this recent concrete technology which has a high hydrostatic pressure. Unfortunate planning details caused the concrete to be dry and far from the liquid quality which was expected. The 'old' concrete was difficult to pour and caused a pour surface quality.

The columns have remained on the campus of RDAFASA

1.1 SINUS COLUMN

Eg

Authors :Mark West and Aynslee Hurdal, (CAST)
Assistant Anne-Mette Manelius and assistance from E.Pihl & Son foreman

What
Showpiece, which introduces radical formal and surface consequences by very simple means. Three-metre tall column, Ø 30 cm, cast in PP weave. The formwork tube is closed vertically with laths and plywood cut in a sinus curvature. Tied ropes pinch in the formwork surface in a few places.

Process:
The PP weave was cut and shipped to Denmark from Canada. The sinus curves were cut, and holes were made through the sandwich clamp. The closure lath was placed vertically.

Evaluation:
Made a virtue of necessity and made a decorative element out of the constraining element that closed the fabric.









Details of the Sinus Column and the column cast in Fab-form. Pour concrete quality caused numerous blowholes.

1.2 COLUMN CAST IN FAST-TUBE™

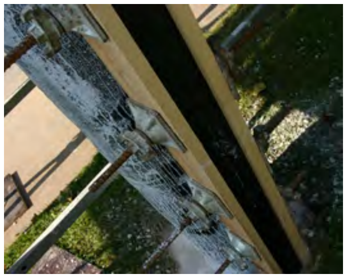
Eg

Authors: Mark West and Aynslee Hurdal, (CAST) , Assistant Anne-Mette Manelius and assistance from E.Pihl & Son foreman

What:
Demonstration of formwork product in polyethylene by the Canadian company FabForm Industries.

Process:
The tube was rolled out and cut to the length of the height of the column. The overlapping flap was attached to a wooden lath which was then placed vertically. The stripping of the formwork was very simple - when the plastic formwork is carefully cut open with a knife, the plastic surface simply slips off the concrete.

Evaluation:
Very quick and simple way to cast a column - if what you want is the available diameter… no perforation in the fabric - the surface is less smooth than the PP. Industrialized production.







1.3 VOODOO COLUMN

Eg

Authors: Mark West and Aynslee Hurdal, (CAST)
Assistant Anne-Mette Manelius and assistance from E.Pihl & Son foreman

What:
Demonstration of fabric formwork by production of a column with advanced geometry.

Process:
An unfolded funnel was cut at CAST and shipped to Copenhagen. Wooden laths were used as vertical closure devices. Metal bars were plunged into the filled mold immediately after the pour, 'stabbing' it.

Evaluation:
The metal bars made the end-result look less poetic and more like a pierced phallus. Other inserted objects might have a similar or better effect. This column has the least aethetically appealing effect.

LEARNING FROM CAST AT RDAFASA

Notes

These pours were the first ever made in Denmark. Several issues should be kept in mind for future projects.

Technical Issues

Accuracy – the greater the accuracy, the better the result. Perfectly even foundations would have made a big difference as would better quality concrete!!
The uneven foundations caused problems, because the formwork was not long enough to actually reach the ground. Frantic measures were taken to even out the gap, which proved to cause more trouble than if no measures had been taken.

Measures were hastily taken to close the gap. Instead of simply extending the fabric with duct tape, a plywood ring was cut out and placed at the base. It was not level, however, which caused the shape to sag and reveal the underlying conditions of the pour.

Another problematic issue was the use of old concrete. The concrete had already 'burned off,' and it was difficult even to get it out of the truck. This resulted in numerous holes in the concrete surface, which was very different from other reference works.
The 4-cm gap at the base of the form would not have caused a problem if only we had known about it beforehand. The expectation was 'lava concrete' SCC, which would have poured like gravy.

Cultural Issues

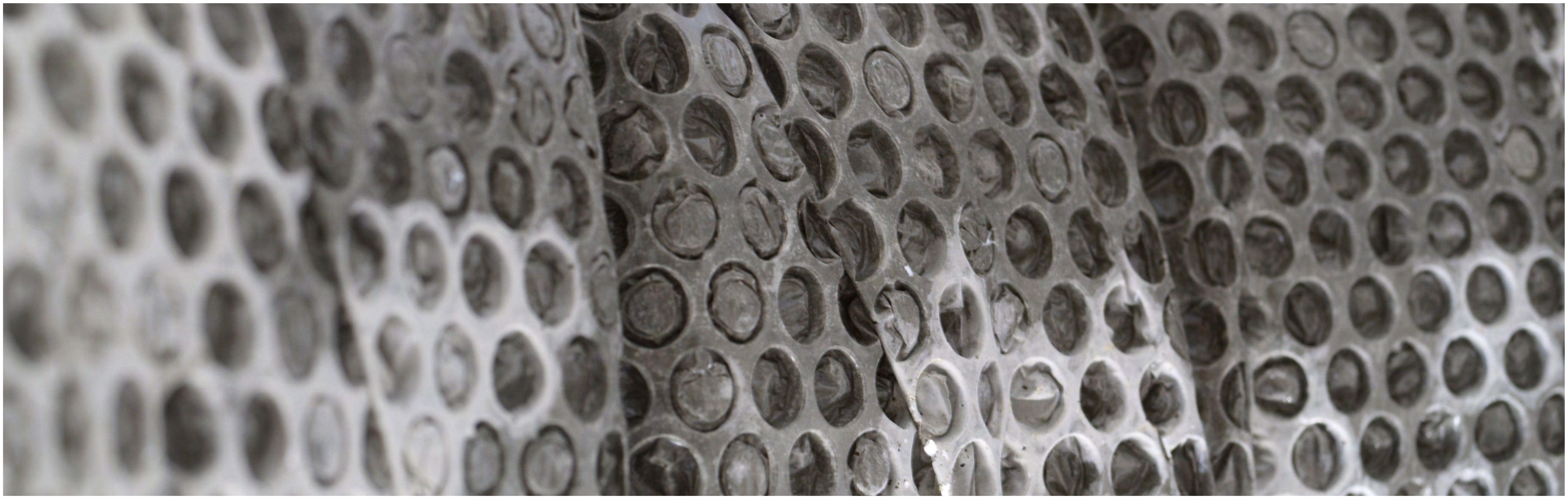
Another cultural difference appeared with the two sculptural pillars.

The Fab-Form product showed less of this – effects could be achieved by twisting or wrapping rope or fabric around the tube. One very positive aspect is the fact that the tube can be cut to achieve the desired height exactly.

One major point was the fact that this was the first time that columns like these had been erected in Denmark. Various flaws notwithstanding, the columns are there, 3 meters tall and robust, with a diameter of 30 cm.

Tectonic Issues

The Sinus Column (1.1) in particular was intriguing due to the direct formal consequences of the chosen technical solution: The 'vertical closure' [see description in Chapter 3] consists of boards – why not simply cut a curve in the board instead of a straight line? I am also fascinated with this ornamental potentiality in other, earlier works by West.



2 / TEK1 2009

Q CH Ed Q Ed CH O O Ed

TEK1 is a mandatory course in building technology for the first year students of architecture.

Where: RDAFASA
When: February 2009

Experiments

Published:
Flyer for the project partners

Reflections

TEK1 2009

Soft forms and sharp edges *(Bløde former og skarpe kanter)*

TEK1 is a mandatory course in building technology for first-year students of architecture at RDAFA. In 2009, the course introduced a ten-day material workshop where students would work with one of four major building materials: brick masonry, concrete masonry, wood or metal. The workshop was organized and carried out by the author together with fellow PhD student, architect Johannes Rauff Greisen and lecturer Finn Bach. The preliminary working days took place at a workshop at the Technical University of Denmark, and the pour took place at the quay in front of the RDAFA.

The workshop served as an introduction to concrete and fabric formwork for the students. The works created at the workshop would be the first of their kind. Available materials were a small amount of PP weave and various types of cotton fabric that had been purchased at a local fabric store (Stof 2000).

A common denominator for the work with fabric forming is constraints as form-givers, for example clamps of various kinds: bolts, elastic string or geometries impacting the surface. Among the student projects, one great idea was to use a geometric pattern in a rigid material attached to the fabric, which meant that the flexibility of the fabric was constrained by the geometry. The fabric became bendable along the edges rather than along a double-curved surface.

Pouring formwork structures one by one, on the quay at the RDAFASA

The filled formwork structures were wrapped in thermal mats to protect against the freezing temperatures. The mats have been reused for TEK1 2010 and TEK1 2011

The assignment for the workshop was 'Sharp edges - Soft curves'. The focus was upon questioning the properties of the formwork materials, textiles and plywood, and produce concrete objects that explored these properties.As part of the assignment, student groups produced reports which can be found on the cd (in Danish).
The assignment for the students was to explore the two materials, concrete and fabric, by making the fabric question the concrete, and vice versa.

The course began with introductory lectures about concrete forming and structural capabilities and a brief introduction to fabric forming.
The teams first had a very brief (one hour) brainstorming phase, where they sketched out various concepts in paper, and finally presented these ideas to the rest of the workshop group. Later, they had to materialize the concepts as ideas for formwork structures and conceive of building methods that would make the concepts feasible.

The teams were introduced to concrete as a material through their work. A few groups produced plaster models first, but all groups produced a concrete object cast in a 30x30cm plywood formwork used for empirical testing at DTU. They tested molds, which they lined and filled with texture-giving materials. A few teams also managed to test initial formwork principles on this scale.
They were encouraged to test their concepts for their concrete piece in a 1:5 scale in plaster – some did this, while others tested their ideas in the concrete box, and yet others did not get this far but mainly tested surfaces. The extent of testing impacted the subsequent process.

Prior to the workshop I had an ambition of testing the quilt point method because it had been used to build the largest structures yet (Unno and Chandler) and seemed to be a simple way of controlling the thickness of structures and obtaining an ornamental effect. One team pursued this idea (Clamp Wall 5.2.1) with a simple and strong approach. Anything more would be a bonus – I did, however expect to see the students experiment more with perforation of the concrete and advanced geometric forms than they did. In response to the concepts of the student projects I chose to produce a small piece as well, which experimented with perforating concrete and also introduced a bit of a span. (Bench 2.7)

Participants

64 architecture students, RDAFASA

Organization and teaching

Anne-Mette Manelius, Johannes Rauff Greisen, Finn Bach, Institute of Technology, RDAFASA
Assistant, Jannie Bakkær Sørensen, architectural engineering student, DTU

Concrete sponsored and delivered by Unicon Beton

2.1 CLAMP WALL

Q

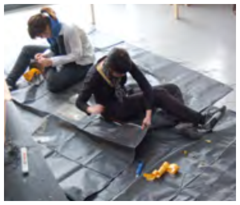
Students: Katrine Dilling Holst, Magnus Maarbjerg, Iris Laxdal, Viktor Harald, Andreas Pilavachi Osterheld, Rebecca Nakayama Karstens

What: The aim was to produce a wall as a 5 cm thick and 200 cm tall free-standing piece, which required considerable depth in order to remain standing.
Intentions: to explore the flexibility of fabric formwork; to maintain uniform thickness despite variations in formwork pressure; to produce a free-standing wall

How: The aim of producing a free-standing wall was achieved by applying a large 'swung' to the bottom and thus obtaining good depth in the structure.
Clamps were placed at different intervals th roughout the piece, thus telling a story of the pressure of wet concrete during the pour: There are more clamps at the bottom of the form and gradually fewer toward the top.

The wall is S-shaped at the bottom and straight along the other edges, fabric was tensioned and constrained by clamps made of plywood and screws. Clamp tubes were 5 cm long electrical tubes.

The piece used very little material to obtain its structure; it had the edges 'controlled' - three straight ones and one curved; the surface had but a few tiny holes and a playful surface.



2.2 HEXAGONAL CONE

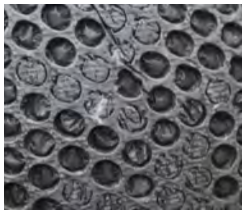
CH

Students:
Bjørn Askholm, Anders Præst, Berit Funk, and June Lima Amalie Algren

What: The project combines woven polypropylene and plywood sheets to test the formal effect of the poured, heavy concrete upon flexible materials. Secondly a number of surfaces lines the formwork in order to test different material effects on the concrete surface.

How: Three pieces of fabric and three plywood pieces were put together, and texture materials were attached to both fabric and plywood. Fabric and wood were attached with staples and screwed onto a lath. The rolled-up pieces created a hexagonal cone with a pointy tip, which was further supported by an exterior frame.

Reflection: The team took the experimental brief very seriously and applied numerous experiments with the structure. It was an example of composite formwork, and the formwork materials were viewed structurally. The other level of the experiment was the surface. Surface experiments blurred the exploration of pliable plywood because extra layers of material added stiffness to the form. It would be interesting to use even thinner plywood and to experiment more with geometry. - How to stitch materials together? - How to support thin plywood? Or possibly use sheet steel instead, which has better tensile strength?



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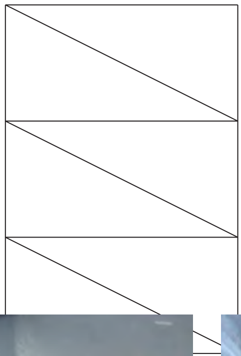
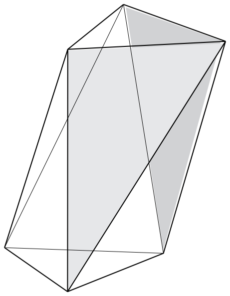
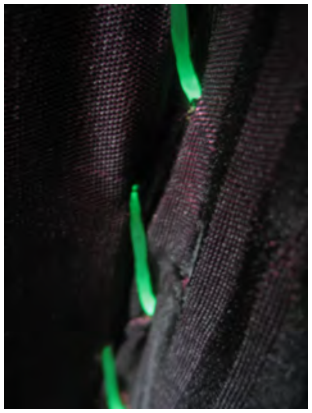






2.3 GEOMETRICAL ROTATION Ed

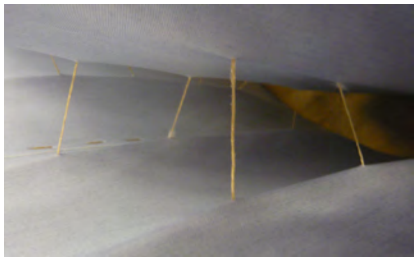
Students:
Iselin, Nicolai, Nicholas, Liv, Annemette

What:
The intentions were to achieve an advanced and unpredicted geometric form by joining equal triangles cut out in 6-mm plywood and allowing concrete to deform the 'rotated geometry'.

How:
The sides of the triangles were taped, stapled and stitched together with nylon wire. The interior was lined with upholstery fabric.

"fibers from the pink stripes got stuck in the concrete and thus gives the concrete a visual relation with its formwork." report (translated by AMM)

Thought:The team miscalculated the volume, so the final form was smaller than 100 liters they had anticipated. The geometric principle could benefit from being scaled up and the number of triangles multiplied.



2.4 S-MATTRESS Q

Students: Olafur Olason, Andrea Brækkan, Annette Byberg, Peter Willemoes, Sofie Madsen.
What: The aim was to use flexible formwork to give an illusion of softness in a hard material. The piece is cast as a miniature wall with fabric suspended between two plywood sheets with a slit the shape of the 'wall', 'Beaver' nylon suspended between the plywood sheets. Fabric constrained with string. Would the space inside the fabric vanish if the fabric bulged too much?

How: Cube 60x60 cm
Fabric suspended between plywood sheets with the wall outline cut out. Suspension from wooden laths and stability provided by rigid sides on the cube.
Pour performed very delicately in order to keep string clamps from blowing.

Sketch model: No plaster or concrete - cardboard and sand in 1:5 didn't do the trick – possibly if sides had been thin nylon fabric in stead of 'bordpap' , the deflection could have occured which would foretell the imlpotion (?) of the final piece?.

Lessons:
The interior of the unfilled form showed a beautiful space. The finished piece became less spatial because the form sides bulged so much that the space in between vanished – it even proved impossible to remove the suspension laths.
The principle tested straight corners and curves, concave and convex shapes.
The principle could have been more spatial if the team had used the entire EU pallet instead of the cube.

2.5 SEAL

Students:
Christopher Slettebøe, Martin Larsen, Kasper Kristensen, Yasemin Yilmaz, Berit Skov Nørgaard, Lars Bramsen

What: Aim to create a concrete element with a crystalline yet organic surface

How: 6-mm triangular plywood disks were stapled onto PP weave in order to create a flexible and facetted surface. The membrane was hung from a frame and manipulated with a few poles. Concrete was cast on the fabric surface.

The project shows a composite formwork which combines materials with different properties. It is an interesting combination of material properties creating edges in a formal language otherwise derived with catenary curves.
The group did consider using the formwork for a vertical cast but chose the horizontal pour – it would be highly interesting to see the technique used vertically.
For production on a larger scale, the technique would have to incorporate a more automatized placement of the geometries, possibly by temporarily attaching the pieces to a mesh like the mesh mats used for bathroom tiles.
Other geometries and scales could be tested, as could other materials and material properties.

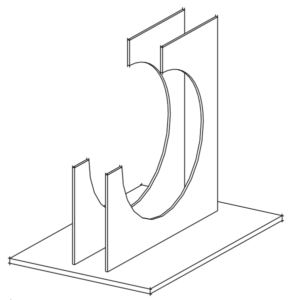
2.6 BIG C (PLYWOOD/ BUBBLE WRAP)

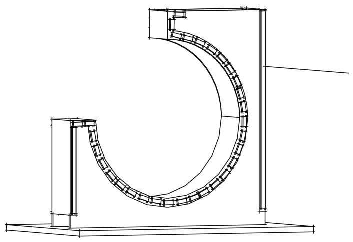
Students: K eyla Berti Lange, Isabella Kleivan, Katrine Jacobsen, Kim Lenschow Andersen, Høgni Laksáfoss, Sara Christensen, and Edit Fodor.

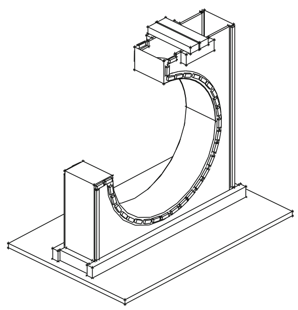
What:
Exploration of rigid and soft formwork materials. Wall with fabric sides. Surface properties derived with bubble wrap plastic.

How:
Two C-shaped sides of 12 mm plywood connected with pp weave to a 200 mm width. The connection is lined with bobble wrap.

The experiment worked well on this scale. If it were scaled up, more intricate figures could be cut out in plywood and connected using PP.. Furthermore, the two plywood sides do not have to be identical, which means that double double-curved 'connecting' surfaces are simple to achieve.
The team used techniques from CAST to tighten the PP weave. These connections could definitely be scaled up and were over-dimensioned (encouraged by me…). The report illustrates all the connections beautifully.







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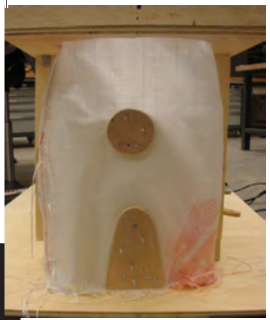


2.7 BENCH

Author:
AMM with assistance from Janni Bakkær Sørensen, stud. eng

What:
The bench as a structure includes a span and two vertical supports. The aims here were to work with perforated columns and a beam-type span and to construct everything within a very short time frame.

How:
A span was created with plywood as support; a slit was cut out to create a fin and increase structural height. Holes were cut out for the legs/columns. Clamps were attached, and the base was attached to the platform. Woven plastic was used as formwork.

The perforations worked well; the legs were not vertical due to insufficient accuracy during construction. The intended slender slab was difficult to obtain, and the surface of the bench was not smooth enough to serve as a seat.
The advanced geometry of the finned slab would benefit from more tailoring, i.e. being put together by two pieces to avoid folds in the fabric and to achieve greater accuracy. Fabric was difficult to remove from folds. - The experiment would benefit from covering a longer span where the 'fin' would come into play. Possibly a future assignment for engineering students?

2.8 GRANDMA'S CURTAINS

Students: Christian Ehrenfels, Frida Gunnarsson, Hella Kooij, Kirstine Bojsen, Sofie Castler, Solveig Sigurdardottir

What:
The aim was to create a vertical U-shaped element with contrasting surface properties defined by rigid and soft formwork and to test the tensile strength of various fabrics.

How:
A rigid outer structure and an inner fabric mold made of different fabrics.

The fabric was insufficiently tensioned and proved of poor tensile strength, most likely because it was aged and fragile. Hence the formwork blew because the fabric tore. The form formwork was not repaired and remained 80 cm high instead of the intended 200 cm.
The aim of testing different fabrics was carried out to a certain degree – the fabrics were much the same. Measures would have to be taken for the mold to be repaired or for taking steps if a fabric type proves too fragile and rips. What remained were surface studies of fabric with prints. The fabric was difficult to remove where bulges caused it to meet, so some fabric remained in the folds.

The piece is one of many with a formal ambition of obtaining contrasts in the concrete form.

2.9 HAM ARCH

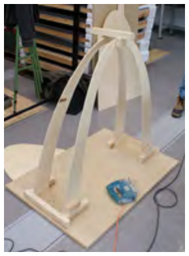
Ed

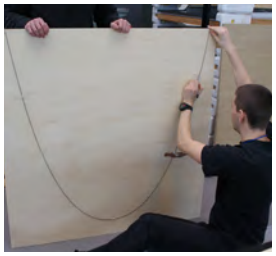
Students:
Susanne Kaas, Louise Kawalla, Arendse Agger, Håvard Sagen, Rasmus Emborg.

What:
Design aim: Build an arch, and cast it vertically. Material questions were to let gravity affect the formal outcome.

How:
Arch designed by drawing a catenary curve from hanging chains. Sandwich construction in which the arch is shaped by two plywood frames between which fabric is suspended. Rope is wrapped around the form as a constraining method.

Another composite formwork –. TThe fabric contains the concrete, and the shape of the overall structure is defined by cut, rigid plywood. Problems with removing formwork were mainly due to a lack of basic tools.





2.10 PAPER AIRPLANE

O

Students:
Unknown, Students did not make a report

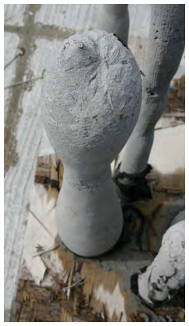
What:
The team was inspired by origami and wished to create a shell that looked like a paper airplane but was made out of concrete.

How:
A rigid mold which resembled a paper airplane was constructed and filled with concrete. The team did not hand in a report, so little documentation of the process is available.

The team had an interesting structural idea which could have led to an interesting structure. With reference to techniques from working with gauze and plaster of paris and Concrete Canvas, it would have been interesting if fabric was used as reinforcement, impregnated with concrete and then folded.

Techniques of casting FRC elements could be used. CAST has developed solutions in which the flexibility of a membrane is used to form a shell at 'the perfect time', just before the concrete sets (See 5.2)







2.11 STALACTITES / STALAGMITES

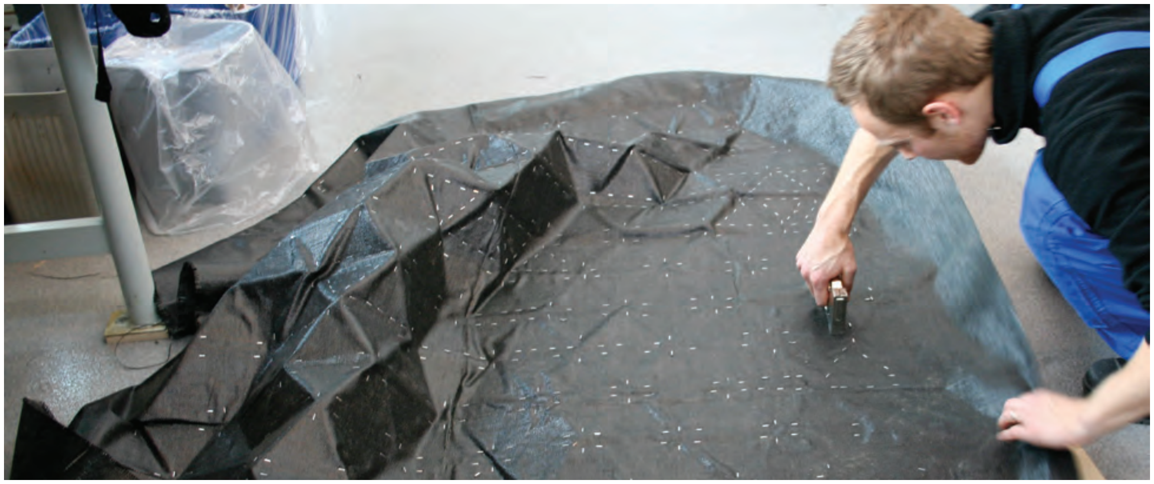
0

Students:
Unknown, Students did not make a report

What:
Literally pouring concrete in different socks and stockings made from wool, cotton, nylon etc. And with different modes of restraining.

How:
Socks are hung from a plywood rig and filled with concrete by hand. Each 'stalagtite' is reinforced with an iron bar.

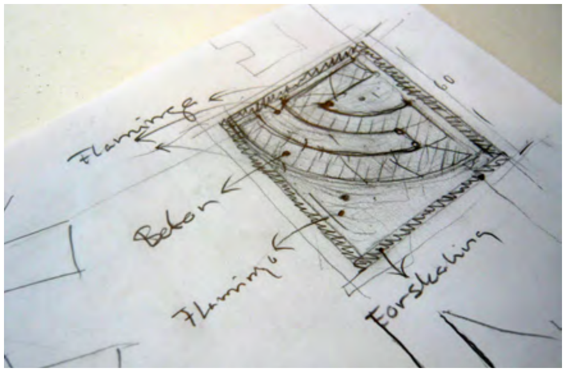
The structure is flipped and the formwork socks are stripped off. The woolen textiles proved difficult to remove from the surface.

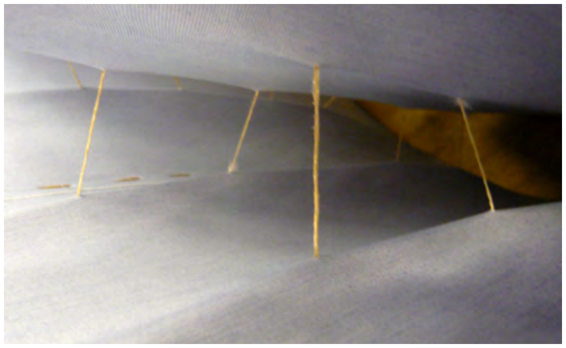


LEARNING BY DOING
CONCRETE AS AN ARCHITECTURAL MATERIAL - WORKSHOP
AT THE ROYAL DANISH ACADEMY OF FINE ARTS, SCHOOL OF ARCHITECTURE
FEBRUARY 9-13 2009

LEARNING BY DOING
CONCRETE AS AN
ARCHITECTURAL MATERIAL

Article made to communice the workshop activity to industrial and academic parts, material sponsors





LEARNING BY DOING – CONCRETE AS AN ARCHITECTURAL MATERIAL
By Anne-Mette Manelius

How to tailor make concrete forms out of flexible materials – and how is flexible formwork challenged and changed by heavt fluid concrete?
This question was the focal point during a week long workshop for 60 first year students at the Royal Danish Art Academy's School of Architecture.

The aim of the five day workshop was to introduce the students to the world's most commonly used building material, concrete – which better way than working hands on.

The assignment was laid out as an experiment in which the students in groups were to construct concrete formwork exploiting textiles and/or thin, bendable plywood – easily manageable into a form of complex geometry. But what happens to the form when filled with concrete wich density is almost two and a half the one of water.
Wooden laths and plywood were available to keep the formwork together.

During the first two afternoons the groups brainstormed and shared their thoughts on fabric forming principles. Without much introduction to references from the fabric formed world the ten groups quickly focused their work.

Little models were constructed and tested with sand and plaster of Paris. This gave a good feeling of what would happen in a larger scale and adjustments of the design were made before building the large formwork.

Overall the experiments investigating structure and surface could be devided into three categories:
- >> Concrete shapes textile
- >> Combining boards and textiles
- >> Free form: textiles and clamps

The object were to be quite small: fitting onto a EUR pallets of 80x120 cm and not heavier than 1-200 litres – within these restrictions a variety of textiles were used spanding from grandma's curtains to heavy sheets of woven polypropylene, socalled geotextiles.

During the week the rest of the class of 200 students studied brick work, timber and steel. These other workshops more than filled the woodshop facilities at the Academy.
We were fortunate to use facilities at the technical university faculty of building engineering. This again had the benefit to show and use a concrete work facility that is long missed at the academy!
Forming principles and materials were cast in self compacting concrete in little rigid forms.

On Friday morning the formworks were moved and placed outdoors on the quay on the academy campus. Most of the groups had expected to fill the forms by hand and buckets – 1.5 m3 ready mixed concrete came by truck of a size that quieted the crowd.

The sturdy concrete handler knew how to work the conveyor belt and group by group directed and filled their form in close cooperation with Mr Concrete.
We cut a slit in the buttom of a bucket and created a funnel for acurate pouring.

The weather was sunny and 0 deggrees Celcius. All the casts were wrapped in thermal mats to avoid the concrete to freeze before hardening. One form couldn't cope with the pressure. Grandma's curtains tore and concrete flooded the quay.

Vibrator sticks were used to compact the concrete. Additionally, the fabrics were vibrated – massaged is a better word - from the outside by hand. Inspired by japanese fabric formwork architect and builder Kenzo Unno, punching sticks were made by padded wooden laths.
The permeability of the fabrics allows eccess air and water to filter through the formwork.

The physical result of the workshop is a number of concrete structures left behind on the quay. Each has its individual appearance and bear witness to the fluid origin of concrete, and to the variety of structural possibilities of concrete cast in flexible formwork.
The used materials have left traces in the concrete surface – plastic bobble wrap, the structure from the woven textiles as well as dye transfered to the concrete.

A few days work has produced interesting forming principles worth exporing further. Fortunately the young architecture students have many years ahead tp experiment.

The workshop was planned and carried out by researchers at the Institute of Architectural Technology at the Royal Danish Academy of Fine Arts, School of Architecture in February 2009.

The workshop recieved kind sponsorships from concrete company Unicon and geotextile company Bluepack.

Written by industrial PhD Anne-Mette Manelius
/ E. Pihl & Søn
/ Schmidt Hammer Lassen Architects

LEARNING FROM TEK1, 2009

Reflections written after the workshop

This workshop consisted of more than 60 students, divided into 9 groups. Time was very limited. The schedule actually specified pieces of no more than 100 liters. This was based on the initial idea of pouring at the Technical University of Denmark and later moving the pieces. In fact, the formwork structures were moved, and a truckload of concrete arrived on site.

Some of the principles had a greater potential than was exploited, and as it turned out, most of the projects could have benefitted from being built on a larger scale. The good thing was that most forms survived – however, a great deal could have been learnt from failures… Scaling the structures up would have transformed the sculptural pieces into more structurally and architecturally challenging structures.

In terms of method, the teams who had managed to test elements of their concept in initial plaster or concrete models/pours definitely finished the workshop on a more advanced level.

In experiments with geometries, the challenge lies in the joints and in how the materials are connected. The flexibility is limited to the flexibility of details in joints and constraining methods.

Several of the concepts would benefit from being tested at a larger scale. During initial planning the idea was to pour in the lab at DTU(building 119). In stead we were sponsored by Unicon factory concrete and the formwork structures were moved to the site on the quay in stead of the finished elements. This gave more time for the students to prepare their formwork and it offered to option to pour a lot more. When this was realized the other issue regarging available materials became important. We only had 6 square meters of PP weave which somewhat limited the scale of certain objects.

Tectonically

Projects that followed the brief and questioned the relations between the poured concrete and the variable flexibility of the formwork materials were the most interesting. This was in contrast to projects that pursued a fixed shape. (ARE THERE ANY?)

Documentation

The student reports form an invaluable collection of thoughts and documentation of process as well as the 'results.'
Teams that were able to draw their formwork structures proved to be more on top of things and tended to have the simpler concept ('Show it, don't tell it').

Teaching

For future workshops, all groups should be encouraged to test their ideas in initial models.

3 / THE AMBIGUOUS CHAIR

Q Q

Aim to produce concrete structure which could only be cast in fabric;
to test existing clamp technique; to use furniture fabrics to create a surprise encounter with concrete

Where: Workshop and concrete facilities at DTU (Danish Technical University)
When: March 2009

Published:
Preceedings from Structural Membranes 2009, International Conference on Textile Composite and Inflatable Structures.
Blog posts and a chapter in the book
Stuart, Christopher, ed. 2011. *DIY Furniture: A Step-by-Step Guide*. Laurence King Publishers.

Exhibited: Scanbuild 2009; Schmidt Hammer Lassen Architects; Institute of Technology (RDAFASA)

Concrete recipe made by researcher at the Technical University of Denmark

3/20/09 DTU HS 3.xls

	90 ~~kg~~ L					
	Density KG	F (by weight)	F (by volume)	V [cm3]	M-%	m [g, kg]
Cement	71,71 3.150	1	n/a	32.88	41.00	**103.58** 36,85
MS	14,34 2.400	0.2	n/a	8.63	8.20	**20.72**
Sand	25,10 2.600	0.35	n/a	13.94	14.35	**36.25**
Quartz powder	25,10 2.761	0.35	n/a	13.13	14.35	**36.25**
Water	35,85 1.000	0.5	n/a	51.79	20.50	**51.79**
a	1.060	0.005	n/a	0.49	0.21	**0.52**
b	3.150	0.00112	n/a	0.04	0.05	**0.12**
Fiber	2,34 1.300	n/a	2.00%	2.60	1.34	**3.38**
Air	0.000	n/a	5.00%	6.50	0.00	**0**
			ml, liter			**kg**
	(175,15)	**Target vol.**	**130**	130.00	100	**253**
w/c	0.50					
w/(c+FA)	0.42					
w/solids	0.26					
(c+FA)/solids	0.77					
density	1.94	kg/dm3				

Erik,

here is the mix for Tuesday.

Gregor

3. AMBIGUOUS CHAIR

Author:
Anne-Mette Manelius, assistant Jannie Bakkær Sørensen

What:
The aim was to produce concrete structure that could only be cast in fabric; test existing clamp technique; use furniture fabrics; and create a surprise encounter with concrete.

How:
Fabric tensioned between plywood sheets and connected by means of the quilt point method. Concrete was poured on vibrator table. The concrete was ECC (*Engineered Cementicious Composite*) reinforced with PVA (*Poly Vinyl Alcohol*) fibers

Initial models:
Concept model 1:5 in fabric and cardboard. 'Pillow' test pieces which tested types of constraints, fabric perforation, slenderness and the use of steel frc.

Lessons:
We should not have cast two chairs at the same time!! One blew, which made us terminate the entire pour.

3.1 S-FORMED CHAIR

Q

3.2 ∂-FORMED CHAIR

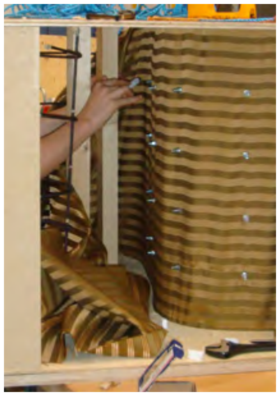
Q

The experiment is illustrated extensively in the report on the cd

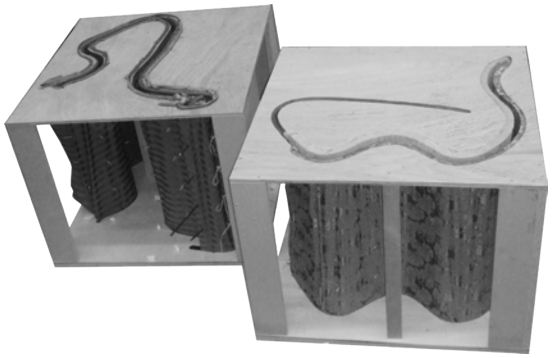


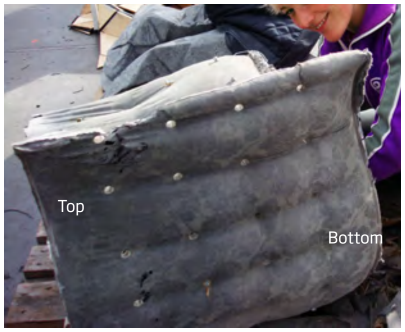




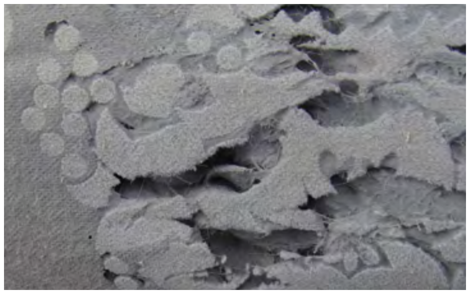












AMBIGUOUS CHAIRS CAST IN FABRIC FORMED CONCRETE

ANNE-METTE MANELIUS*

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Key words: Fabric Formwork, concrete, Innovative Design, Discussion, Affordance.

Summary.

On the basis of a specific experiment with a new casting technique for concrete structures, this paper discusses explorations of materiality as a way of generating discussion of the use of new technologies.

FABRIC FORMWORK FOR CONCRETE STRUCTURES

Fabric formwork is a building technology in which sheets of woven textiles are used as flexible, strong and lightweight formwork for casting concrete structures on site or as prefabricated elements. The PhD project on which this paper is based further elaborates research by pioneer in the field: Professor Mark West, University of Manitoba[1], Professor Remo Pedreschi[2], University of Edinburgh, and build works by Japanese architect Kenzo Unno (fig. 1)

The technology has been used for building only in a few cases[3]. Issues regarding production, structural behavior and aesthetics of fabric forming have yet to be examined further before architectural perspectives and the development of yet unknown structural solutions can be fulfilled in building. The aim of the PhD project is to further discuss the development and possible implication of the building method in contemporary architectural practice.

The use of prefab concrete elements is prevailing for building in Denmark; the use of exposed concrete surfaces and on site cast concrete structures less so, this due to a long tradition of facades with exposed brick; high cost of skilled labor; and the social image of concrete architecture which is still heavily influenced by large scale prefab housing schemes of the 60s and 70s - Works done hastily and inhabited by socially challenged groups of people. In order to generate discussion of the architectural perspectives of a new building method it seems crucial, constantly to expound on aesthetical as well as technological and structural aspects which are balanced in an integrated architectural practice. Besides these issues, the social notion of concrete can be seen as a barrier for initiating a discussion of the implementation of a new concrete technology: if nobody likes the idea, never mind how clever the technology.

POLARITY BETWEEN MATERIALITY AND TECHNOLOGY

The Industrial PhD[4] project has two commercial partners involved in the project: a large contracting company and an architectural office respectively representing the basic polarity of the project between the terms Technology and Materiality.

The technology pole contains subjects of material properties, techniques and praxis, thermal mass, surface properties etc. Questions related to the production and technical aspects of the project regard how to produce fabric forms and fabric formed concrete structures; what is possible and how to do it e.g. seen in relation to current building practice. A central technical issue is the production of defined tension geometries when wet concrete is poured into a tensile membrane. Another aspect comes from casting in woven fabrics. During curing excess water and air bubbles filter through the formwork which lowers the water/cement ratio and in effect leaves a smoother, less porous concrete surface. This technical advantage connects to the materiality pole.

The materiality pole of the project has issues regarding the perception of space, shapes and surfaces, optic vs. haptic appearance, indoor climate etc. In terms of architectural articulation, concrete is nicknamed ‘Liquid stone’ – poetic traces of the becoming of concrete shows on the surface as imprints. The technical filtering aspect mentioned above, adds a layer of narration to concrete architecture because the character of the tensioned fabric and its woven detailing is articulated on the concrete surface.

OXYMORONS AS EYE OPENER

In the following I’ll elaborate on associations with fabric formwork as an oxymoron; a term which contains two terms of opposite meanings, the terms fabric and formwork. The architectural exploration of the oxymoron is hereafter suggested as an example of a strategy for creating a new perception of concrete and initiating a dialogue on what concrete architecture cast in flexible fabric forms could be.

Textiles can be seen as something light and delicate which can be draped and tailored. According to Semper, the general purpose of textiles is to cover, to protect, and to enclose[5]. This broad definition covers a multitude of functions: covering the body, the floor, furniture, a spatial enclosure etc. At a more everyday level, the function of textile varies greatly with the addition of highly technological textiles used as concrete reinforcement, gas filters, ground securing and more delicate functions at a small scale as replacement for ligaments in the human body[6].

Concrete formwork has the function to enclose as well, however only temporarily as it contains wet and heavy concrete until cured. Formwork can be considered very sturdy, manual, rigid, and heavy, a temporary structural system build up and torn down after casting. Technically formwork system varies from being completely handmade – the more advanced the form, the more handcraft is needed to build the formwork in wood – to formwork systems in aluminium frames and plywood – to aluminium all over.

The specific experiment is the design and production of two fabric formed chairs. The exploration includes presenting to the observer physical objects of a familiar function and scale, but containing ambiguities of the materiality, construction and affordance[7]. The mentioned ambiguities concern optical appearance vs. the haptic perception and information which comes when touching the object and from the act of sitting down.

Using fabrics for furniture and thus getting some associations right that come with the function of a chair: Fabric, patterned surface structure and a bulging surface are all associated with the notion of an upholstered chair such as the Chesterfield.

It seemed a natural choice to use upholstery fabrics for casting a chair in fabric formed concrete. Architecture students at University of Edinburgh have studied the aesthetic surfaces of concrete cast in a number of conventional fabrics bought at the local fabrics store, including both very thin and cheap materials and more sturdy fabrics for upholstery. It was the intention of using upholstery fabric that the pattern from the fabric would transfer to the concrete surface making the appearance of the chair even more ambiguous to the observer.

Concrete – and Chesterfield furniture - is associated with something heavy, sturdy and solid. It is load bearing, however not usually of the small load of a person, but more likely a beam or a roof. The chairs were cast in fibre reinforced concrete. With flexible fabric formwork the chairs were designed and produced as a folding plane with thin dimensions, a big cantilever as the seat and perforated surface for water to run off. This shell structure was intended with a fragile look not associated with concrete

MATERIALITY AND REACTION

The gestalt psychologist Kurt Koffka wrote that "Each thing says what it is"[8] but the thing may lie.[9] The deliberate exploration of this statement is the essence of the described experiment for creating discussion of fabric formed concrete. When observers are confronted with the two chairs it has been evident that there was a shift between expectations derived from the optical appearance of the objects versus the actual haptical information obtained from the experience of engaging with the object – touching and sitting (fig2-5). As my conclusion I'll mention a few remarks from observers: "Is the fabric still on the chair?" The remark reflects how the concrete surface has a tactile feel, defined fabric appearance, transfer of patterns and even colored fibres – "this could not possibly be concrete". Another observer is intrigued: "I looked at the chair and in my head I knew it was concrete and couldn't understand that it wasn't fabric. Then when I sat on it, in my head I knew it was concrete and would be hard but I was still surprised to find that the chair wasn't as soft as it looked."

While one of the two casts resulted in a functional chair, the other one became an object with only an abstract notion of the functionality of a chair; instead showing, more directly, aspects of materiality and technology (fig6). Several clamps blew out of the fabric form. This lack of constraint to the fabric caused the form to fill more with concrete. When the cast was terminated the bottom was more than ten times thicker than the unfilled top. The fibre reinforced concrete created a paper thin surface at the top; a hollow cardboard feel when tapping on the fragile surface as opposed to the solidity much associated with concrete.

It is the assertion that a surprising encounter with concrete can be a generator of curiosity and discussion. Confusing the senses activate new levels of perception and emotion, besides previous experience and tradition of the observer. The discussions concern the perspectives for using flexible formwork for new types of structures, forms and surfaces.

Figure 1: Fabric formed wall by Kenzo Unno

Figure 2: The author seated in a fabric formed concrete chair

Figure 3: Chair cast in fabric formed concrete

Figure 4: Detail of concrete surface with imprints from the woven fabric pattern of the formwork

Figure 5: Detail of concrete surface showing pattern and fibres from the used upholstery fabric and exposed clamps holes.

Figure 6: Chair cast in fabric formed concrete. The formwork blew while casting.

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1 West, Mark and CAST: (2009) www.umanitoba.ca/cast_building/index.html

2 Pedreschi, Remo & Alan Chandler (eds) (2007) Fabric Formwork, RIBA Publishing

3 West, Mark (2008?) “Kenzo Unno, Fabric Formed Walls”, www.umanitoba.ca/cast_building/assets/downloads/PDFS/Fabric_Formwork/Kenzo_Unno_Article.pdf

4 An Industrial PhD project is a special, company focused PhD project. The project is conducted in cooperation between a private company, an Industrial PhD student and a university. http://en.fi.dk/research/industrial-phd-programme

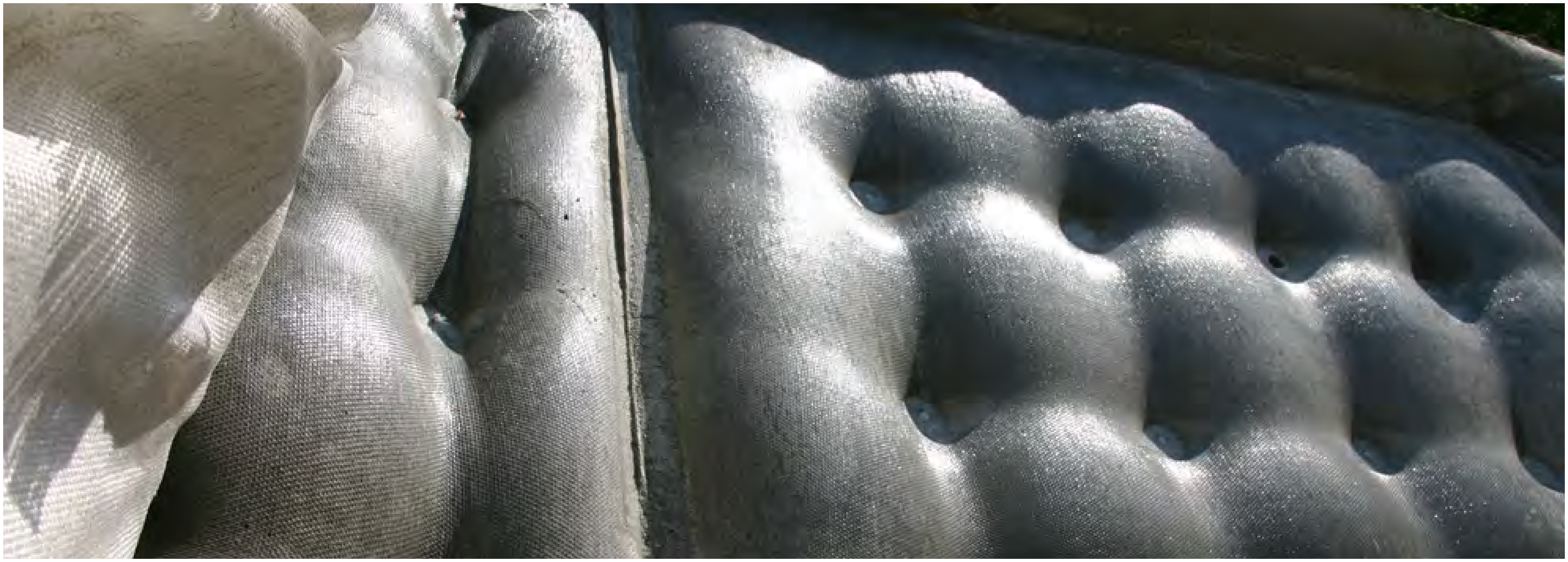
5 Semper, Gottfried (2004, org 1860: ”Der Stil in den technischen und Tektonishen Künsten”): “Style in the Technical and Tectonic Arts; or, Practical Aesthetics”, Getty Publications, p. 113

6 McQuaid, Matilda (2005) “Extreme Textiles: Designing for High Performance”, Princeton Architectural Press

7 Gibson, J.J (1977) “The theory of affordances” IN R.Shaw & J. Bransford (eds.), *Perceiving, Acting and Knowing*. Hillsdale, NJ: Erlbaum

8 Kurt Koffka (1935) *Principles of Gestalt Psychology* (1935) publ. Lund Humphries, London, Chapter 1

9 Gibson, ibid p.81



4 / VERMONT WALL

Q

A 10 ft tall L-shaped wall

Where: Workshop at Yestermorrow Design Build School, Warren, Vermont, USA)
When: August 2009

Documentation of procedures and detailing

Published:
Flyer for the project partners

4 FABRIC-FORMED WALL IN VERMONT

Workshop at the Yestermorrow Design Build School, Warren, Vermont

Organized by Sandy Lawton of ISOFF. Co-organized by Mark West. Q

Who:

A workshop team of architecture students, researchers of fabric formwork, including Mark West and Ronnie Araya of CAST

What:

A 10 ft tall wall as the two walls of a cabin for visitors or students at the school. The cabin is to be part of the campus' collection of noninsulated livable course pieces. Others are mostly built in wood. Future workshops will produce a fabric formed frame (beam and 2 columns); non bearing wood and glass walls and a vaulted fabric formed concrete green roof.

How:

Formwork panels were prefabricated and connected on site with:

a) variations over the quilt point method,

b) pilastres between the panes where the fabric is connected by rolling and connected with metal wire

Reinforced with carbon-grid ('c grid')

The pouring technique was a slow pour, which lets the concrete set a little bit between layers – the entire form is filled af few feet at a time – this lowers the formwork pressure and decreases bulges/fabric deflection.

Lessons:

This was the biggest pour I got my hands on during the thesis work.

Problems occurred because there were too many inexperienced members of the building crew and insufficient communication (clamps blew out; vertical supports were left on the inside of the formwork structure; not all clamps were connected; not all plane surfaces had sufficient support). Besides, the concrete was not as ordered – the concrete plant added a retarder to the mix, which of course delayed the setting of the concrete.

Structurally, this was a really interesting sequel to Ambiguous Chairs (2.1-2) because of the similar and time-consuming use of small clamps (the Quilt-point method.

The role of Sandy Lawton as the organizing leader of the construction site as well as participant was too much. There was a lack of delegating the tasks of especially quality control. I recognize problems that I have faced in participating and organizing as well.

The wall is 10ft tall by 35 feet aka 3,3x12meterThe stripped fabric formwork is seen on the ground

Detail of tattoo like imprint of used fabric

Detail of concrete surface during stripping.
The vertical mark is an imprint of the wooden frame

WORKSHOP I VERMONT

Within a weeks time a number of principles were developed and tested in a full scale L-shaped wall; part of a future cabin with two beds for the institution ('højskole') which hosted the workshop.

Woven noncolored polypropylene was used as the formwork. The transparent plastic fabric made it very easy to construct, mark and place washers and impacters and the rebar grid – of course you could see the concrete during the pour as well.

The pour didn't go as planned. The concrete plant had (secretly) added Retarder to the mix in anticipation of a long pour.

The retarder had the effect that the concrete didn't set much at all and the pressure on the form was collosal.

The result was a very long pour; damages to the form and numerous damages on the concrete surface. A lesson learned.

The remaining concrete components for the cabin is the focus for another two workshops: A combined column-beam structure, and a prefabricated GFR-shotcrete shell structure for the roof.

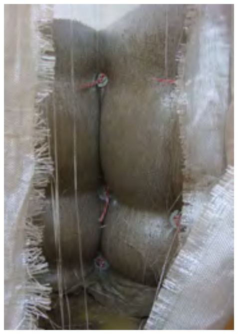
Downscaled documentation/article made for the industrial partners after the workshop

schmidt/hammer/lassen architects/ pihl CINARK
Det Kongelige Danske Kunstakademi, Kunstakademiets Arkitektskole
Center for Industriel Arkitektur

Vermont / workshop / wall
august 2009

Translucsent fabric. Rebar and block-out seen through the fabric

First minutes of the pour



The corner during the pour

The fabric bleeding excess water

5 / CONCRETE FLESH WORKSHOP

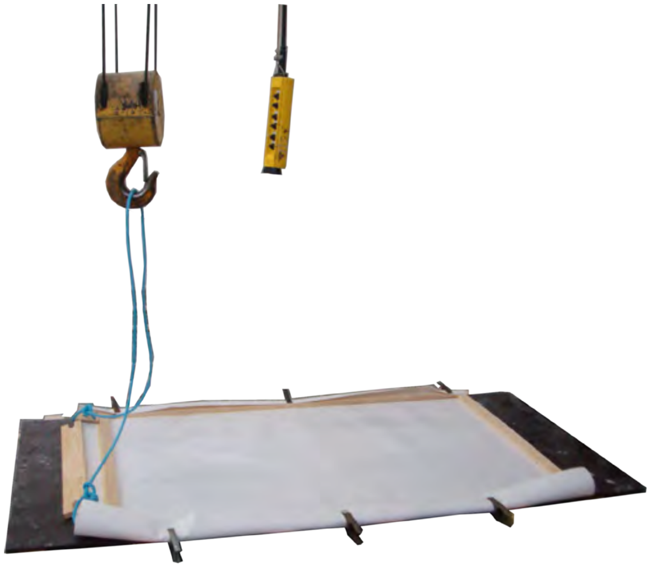
Ed O O

Contribution as guest-cirtic, and participation of workshop

Where: Chalmers University of Technology, Department of Architecture, Gothenburg, Sweden
When: November 2009

Experiments

Published:
Blogposts



5 CONCRETE FLESH

Context:
Workshop at Chalmers University of Technology,
Department of Architecture, Gothenburg, Sweden
Organized by Morten Lund.

Key note speakers at seminar: Mark West, Nat Chard and Nada Subotincic,

When: 2009, November 17-27

Where: Gothenburg, Sweden

Who: Participants were architecture students from Arkitektskolen Aarhus and students of various departments of Chalmers

Learning: The hands-on experimentation demanded a high degree of participation to be successful. The engineering group had another important deadline, which provided more credit than the workshop.

"The Matter Space Structure Studio initiated the workshop "Concrete Flesh", an intense, experimental, hands-on master class based on Mark West's research, lasting from November17to November 27 in 2009.

An interdisciplinary group from the Chalmers faculty, consisting of Peter Lindblom, Karl-Gunnar Olsson, Luping Tang and Morten Lund organized the workshop in corporation with their colleagues Björn Engström, Steve Svensson and Lars Wahlström and the students Vojtech Lekeš and Sanna Nordlander.

The workshop took place in the hangar-sized concrete hall at Chalmers. Its generous space was originally built for testing specimens of structural elements – a kind of real material analysis that has over the years been marginalized by the use of cheaper computer simulations. During ten days in November the large hall was filled with concrete specimens once again.

The students participating in the workshop came from the Matter Space Structure Studio and various departments at Chalmers, and from the Aarhus School of Architecture." (Lund et al, p12)

5.1 CHALMERS COLUMN

Authors: Anne-Mette Manelius, Frederik Petersen, and Kathrine Næss

What:

Because none of the students in the large workshop made vertical objects, the group decided to make a vertical cast. The aims were:

>> to test 'composite formwork'

>> to create a 'drawing' (Frederik's thesis work)

>> use very little materials – or delicate materials in order to demonstrate the simplicity of the technique

>> perforate a column with impacto clamps (as continued Bench legs, (TEK1 2009)

How:

Inner tube made of Spandex, outer 'jacket' made of glass fiber mesh – thick, layered clamps made of plywood. In addition, surface development by cutting holes in outer jacket for Spandex tube to come out. Jacket was laced up with rope.

Hung on a tripod structure.

5.2 + 5.3 SHELLS

Illustrated here and on the opposite page.

Who:

Anne-Mette Manelius, Frederik Petersen, and Kathrine Næss

What:

Testing two techniques as described by Mark West to build a thin, double-curved shell cast in a fabric-formed rigid, concrete mold.

How:

'Fuzzy-backed' material supplied by Mark West, ready-mixed fiber-reinforced mortar, glass fiber rebar mesh, crane, pull.

Concretely blog post before the workshop

CONCRETELY

MY BLOG ON CONCRETE LOVE - CONCRETE AND ARCHITECTURE AND SPECIFICALLY FABRIC FORMING - TEXTILES USED AS FORMWORK FOR CASTING CONCRETE.

TUESDAY, NOVEMBER 17, 2009

Concrete Flesh Workshop, part I

I'm on my way to Gothenburg, Sweden, to attend the largest and most ambitious workshop on fabric formwork that I've been aware of so far during my interest in fabric formwork. Invited researching architects and structural engineers and 100 students from schools in Scandinavia and England will attend the two week workshop at Chalmers entitled Concrete Flesh.

The more I think about the better I like the term – even if I can't discuss it with anyone at my office at the contractor's and keep a somewhat serious appearance – (it's hard anyway being an architect in those hallways). As the subthemes below indicates, Flesh is related to the structure of the body - seperating the containing and protective skin from the structural bones. Flesh is like matter itself; and from Biblical references discusses becoming of Architecture and its---resurrection - well...

Unfortunately I couldn't locate an online program to link to but basically the theme is devided into four parallel explorations:

Flesh and Skin - explorations of the concrete surface;
Flesh and Bones - reinforcement and pre tensioning, fibre reinforcement, etc;
Flesh and Creation: the cast vs the designed form, on casting impossible forms in possible formwork;
Flesh and Resurrection: cradle to cradle perspectives tested through reusing concrete.

Tomorrow is the first day of the workshop and will feature lecturers from the School of Architecture at the University of Manitoba, Canada whom I'm very excited to hear and meet again: Mark West, CAST; Nat Chard, Dean; and Nada Subotincic.

ABOUT ME

A-M

Architect living in Copenhagen, Denmark. Since August 2008 an industrial PhD student working on the architecural perspectives for fabric formed concrete in an industrialized context. Contact me at anne-mette.manelius @ kadk.dk

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[Natalija Subotincic, Freud at the Dining Table – Incarnate Tendencies, plexiglass and bone]

I know that Nada has been working with themes on Flesh and bone. Another reference about bones is my old hero Miguel Fisac whose Bone Beams will be featured among these pages soon!

I'll better pack - off to Sweden in the morning. Come to think of it - it's written nowhere that the workshop will include a single piece of fabric... but, hey - Mr West will be there - I'm pretty sure Ms Fabric will too!!

POSTED BY A-M AT 11/17/2009

+1 You +1'd this

LABELS: CHALMERS, CONCRETE FLESH, MARK WEST, MORTEN LUND, NAT CHARD

Del Rapporter misbrug Næste blog» Opret blog Log ind

Concretely blog post

CONCRETELY

MY BLOG ON CONCRETE LOVE - CONCRETE AND ARCHITECTURE AND SPECIFICALLY FABRIC FORMING - TEXTILES USED AS FORMWORK FOR CASTING CONCRETE.

MONDAY, MARCH 29, 2010

Enchanted concrete trees

This is a second post inspired by the portfolio of Ryan B Coover's Workpod9 studio

[Image of Coover's portable tripod formwork, Photo by Ryan B. Coover]

Concrete Flesh

At the Concrete Flesh workshop in Gothenburg in November, my team build a similar structure to hold our column formwork. We did have a similar blow out and a lazy dysfunctional column as a result.

Our aim was to explore was how little material it would take to exploid the fluid origins of wet concrete

The formwork consisted of spandex and a glassfibre mesh of the sort you put on walls - not much tensile strength to put it mildly. We both tore the mesh for the spandex to bulge out - and added coned clamps to perforate the column.

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[Image: the fabric formed concrete piece was securely hung in a crane before we dared deforming it.
Photo by Frederik Petersen]

The tripod was built to support the weight of the heavily perforated cast. This did work somewhat except for the fact that the formwork expanded and got longer and longer during the pour...

The constraining liner didn't do its job and the clamps were so big that they didn't allow much concrete to pass through and thus ended up acting as hinges

Concrete skin and bones

Reservations could go to the actual structural behavior of the column - in fact column wouldn't really be the term to use because the concrete structure is hardly able to carry it's own weight. The piece explored the workshop themes regarding concrete flesh and concrete skin - completely leaving the analogy to the structural bones out of the picture.

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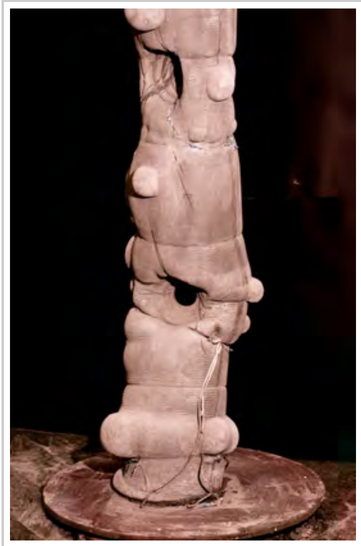


[The stripped concrete piece. It looks like a sick or enchanted, old tree - quite organic indeed.
Photo by Frederik Petersen]

POSTED BY A-M AT 3/29/2010

Recommend this on Google

LABELS: CONCRETE FLESH, FABRIC FORMWORK, FREDERIK PETERSEN, KATHRINE NÆSS, WORKPOD9

6 / TEK1 2010
ELEMENT AND CONNECTION (WALLS)

Ed Ed Ed Q Ed CH Q Q O Eg

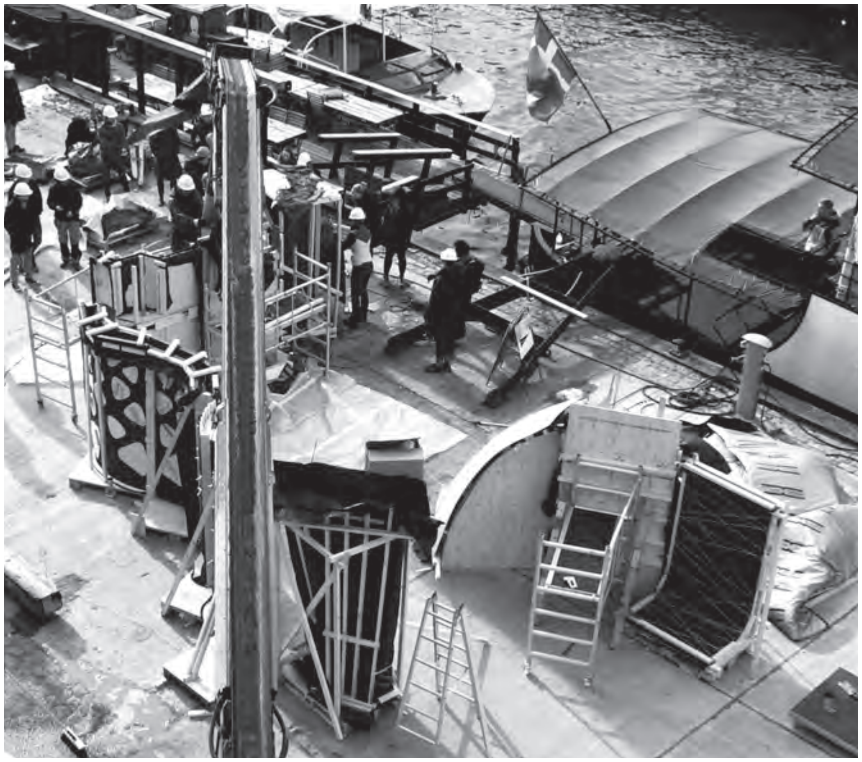
TEK1 is a mandatory course in building technology for the first year students of architecture.

Where: RDAFASA
When: March 2010

Experiments

Published:
Blogpost






Participants

50 architecture students, RDAFA

30 architectural engineering students, DTU – (participated part-time)

The assignment was not given in writing. The article is a blog post describing the assignment

Organization and teaching

Anne-Mette Manelius, Johannes Rauff Greisen, Finn Bach, Institute of Technology, RDAFASA

Assistant, Jannie Bakkær Sørensen, architectural engineering student, DTU

Concrete sponsored and delivered by Unicon Beton

CONSTRAINT AND CONNEXION

Blogpost text

Anne-Mette Manelius, "CONCRETELY: Constraint and connexion - fabric formwork workshop", CONCRETELY, blog, March 5, 2010, http://concretely.blogspot.com/2010/03/constraint-and-connexion-fabric.html. (Accessed 14-02-2012)

These days I'm preparing a workshop for 80 students of architecture to produce fabric formwork and cast vertical wall elements on campus at the Royal Danish Academy of Fine Arts, School of Architecture.
The workshop is a forum in which the students question material relations and their consequences for concrete form and surfaces.

Constraint and connection

The assignment has an overall theme of constraint and connection.
The materials used are flexible fabrics, rigid or not so rigid boards and blanks - and then pouring heavy concrete, of course. Constraints can be understood literally as the means to hold the formwork together and how formwork clamps or constraining frames influence the outcome of the pour. Connection can be understood as the physical connection with a neighboring element but of course also architecturally.

Vertical elements

We'll have 10-12 groups and they will each produce a vertical element of 2 metres and 1,2 with which has to meet the another group's element on one or both ends. This should encourage the students to consider how to work freely between connection points and interfaces between building components.

We will both have architecture students and architectural engineering students from DTU, Danish Technical University.

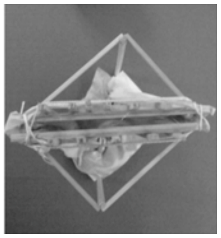
Light prefab formwork instead of heavy prefab concrete
Formwork will be produced at DTU and then transported to the Royal Danish Academy of Fine Arts, School of Architecture where a big concrete truck will deliver concrete and cast all the vertical slabs on site… very exiting indeed. There's a point to be made about prefabrication here –The most widely used building elements in Denmark are prefabricated concrete elements. They are heavy and 'dumb' – lightweight formwork can be prepared in a workshop and easily moved to the site.

The images here are from the workshop last year and here's a link to an article about the workshop.

Feel free to join us during the pour Tuesday March 16th 2010 - and click the TEK1 tag below to read more about the outcome.






6.1 TWIST WALL

Students: Victoria Abelsen, Jens Flinch Bertelsen, Ida Katrine Lyn Andersen, Frederik Engell Holm

WHAT:

The team wanted to make a wall, which twists around its own axis and varies formally from the bottom (zig zagged plan) to the top (straight). The group tested a few similiar principles in plaster.

HOW:

A frame is built of laths and pp weave is suspended between top and bottom. Laths connects top to bottom and work to constrain the fabric. No clamps are used. The laths were exposed to pressure and with no clamps and hence needed further bracing.

The team managed to fill the formwork halfway before concrete was used up on pour day one. Additional pour a few days later caused visible construction joints. The form does not appear to have been compacted the second pour. There are more blow holes on top pour. Furthermore, it appears as if the fabric was difficult to tension with the advanced geometry caused by the difference in 'outline' in top and bottom of the formwork; the fabric could be placed in the middle first and then outwards.







6.2 LEANING ARCH

RDAFASA Students: Elisabet Georgsdottir, Julie Rose, Line Nemming, Anders Simonsen, Kathrine Hede Poulsen, Karen; DTU Students: Theis Andersson, Christian Nielsen, Christina Erikshøj

What:

Slender twisted, leaning, arched concrete slab. Formal language inspired by twisting a strip of paper

How:

A fabric 'Jacket' of PP closed around reinforcement (garden fence). The jacket is embraced or sandwiched between thin (6mm) plywood sheets. A twisted plane is defined between two half-parabola frames of different sizes.

6.3 NET WALL
("WALL DE MORT" IN REPORT)

Students:

Siri Reisæter Rasmussen, Astrid Asmussen, Rasmus Gosvig, Christian Bencke Nielsen,

What:

The original concept was to constrain a fabric formwork for a concrete wall without clamps but only metal frame.

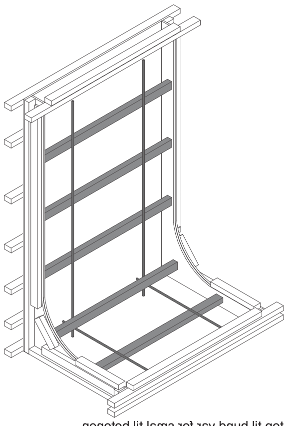
HOW:

Top and bottom sheets of plywood cut to make the plan. Lath used to suspend the sheets
Fabric and 10x10 cm garden fence stretched between top and bottom and stapled under plywood.
Fence on each side connected with metal wire around nodes. Every node connected in the bottom – every other in the top of the formwork structure.
Reinforced only with a couple of ø6 rebars.

All the ties had to be cut off the fence before stripping the form. Further work was necessary to cut the metal wire close to the concrete surface.







6.4 PERFORATED CURVED WALL / S WALL

Q

Students:

Emma Nilsson, Sune Jørgensen, Theis Munk, Else Maria Søeborg Ohlsen, Daniel McLaury, Lennart Dose, Louise Boss, Morten Falbach (2010)

What:

The team is two teams that merged in order to produce a wall twice the size of their given EUpallet.
The aim was to produce a large curved and perforated wall.

How:

PP weave suspended between a wooden frame supported by vertical laths. Block outs of cut EPS and 'washers'/clamps of plywood. Kept together by 'flag line'
During the pour day the team noticed failure in most of the formwork structures filled prior to theirs and further measures were taken to ensure the structure from collapse. The team had underestimated the volume of their form and its expansion. The truck ran out of concrete during the pour and the team decided to end the pour on pour day one.

6.5 HAM WALL

Ed

Students:

Camilla Dahl, Frida Sundbäck, Camilla Stig Christensen, Hanne Michaela Pihl Olsen, Rasmus Gjerløw

What:

The piece attempts a contrast between soft and hard in a rigid and flat appearance of concrete and a soft appearance of fabric. (report)

How:

Rigid back L-shaped frame with a 'lid' of pp weave constrained with 'flag line' across. Tensile strength of the constraining line was ok but with a long elongation, which meant that fabric wasnt constrained much and the intented constraing bulging effect was not overwhelming. The expression was close to the elephant foot in a ballerina's shoe as described above.

Challenges occured where fabric met the rigid frame – this is likely because the constraining system did not work; the fabric connection had to take the entire tension since not much was transfered to the strings.

6.6 THE ILLUSION

CH

Students:

Martin Lukasiewicz, Marte Lyngaas, Jakob von Krogh, Desiré Apelgren

What:

Wall with dimensions and relief detailing to appear as a door. Fabric used as soft formwork to illude melting of concrete

How:

Rigid formwork connected with baggy and draped polypropylene weave where the 'melting' takes place. The piece was cast from the top- the height of the pour assured high pressure for the fabric. It 'swelled.'





6.7 VASTOIN WOOD-FABRIC WALL

Q

Students:

Elin Maria Joensen, Henrik Vedel Larsen, Anders Skjeldal Gaasø, Signe Sand
Report: "Vastoin"

What:

Two wall pieces, one concave and one convex wall with a back of [klinkede/ på klink] formwork boards and the other side with tensioned fabric. Constrained with washers and nylon rope as ties.

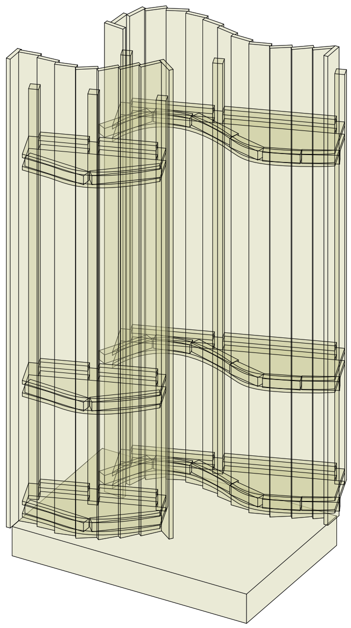
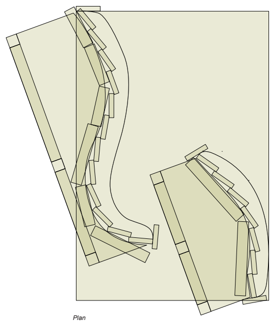
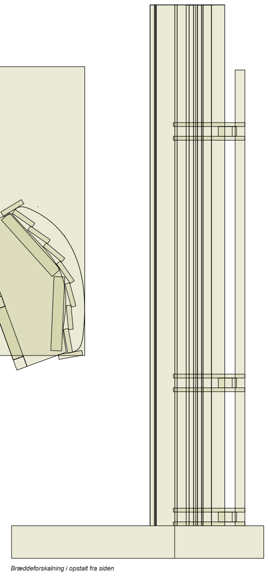
How:

The shape of the wall defined and made into 'rulers' onto which formwork planks are fixed [på klink]. Fabric attached to the rigid back with clamps and the distance fixed using rope clamps.

The team was very unfortunate to be towards the end of the pour day where concrete was finished in the middle of their pour. Before that the formwork blew because fabric was only attached to the rigid back with clamps.

Interesting to test how fabric works as formwork for concave and convex structures. Failures didn't offer the full knowledge to be gained. This is one of the few teams, which produced a rigid yet curved formwork structure.
Vastoin means 'On the contrary in Finnish'





6.8 BUTT (CHESTERFIELD WALL) Q

Students:
Heidi Jacobsgaard Schøbel, Jens U. Jørgensen, Tommy Olsen, Laura Bendixen, Michala Crone, Niels Guenec

What:
Wall piece to show contrasts between rigid and soft formwork: A straight back and a front with bulges inspired by upholstered furniture such as the Chesterfield.

Initial models in plaster:
Models in 1:10 and 1:1 testing the overall expression and the detail in which the clamp is a plug that also perforates the wall.

How:
Rigid back formwork with pp weave suspended across. Clamps function as formgivers and are important for the expression inspired by Chesterfield furntiture. Like most teams this one had focused almost entirely on the most spectacular parts of the formwork – fx in testing the clamp method – with little focus on other and equally vulnerable parts of the formwork. High pressure from the concrete deflected/deformed the lower part of the rigid formwork and screws and fittings were torn out for the form to blow



1:1 plaster model of detail

6.9 PAPER FOLD WALL

O

Students:
Charlotte Marie Raussen, Emilie Salling Kjeldsen, Kristin Søndersrød Ose, Pernille Langevad Clifforth, Stine Marie Rosenborg

What:
Wall piece with over hang – inspired by folded and cut paper

How:
Rigid formwork lined with pp weave.

Initial plaster model:
Several plaster models tested the concept and proved it to be very ambitious to have a cantilevered wall balance in two [spinkle] points.

Lessons:
The structure was very challenging to produce and didn't live up to the team's ambitions. The structure itself proved to be vulnerable. The low corners couldn't cope with the concrete pressure.

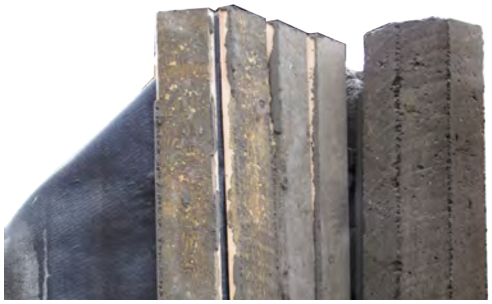
6.10 COMPOSITE COLUMN

Eg

Author:
Anne-Mette Manelius with assistants Jannie Bakkjær Sørensen and Signe Ulfeldt

What: aims of the experiment were to minimize the amount of materials used for anything but creating the concrete form or surface; Create sharp edges in fabric formed concrete; show a direct way of applying fabric formwork to produce convex shapes (columns, curved wall etc.)

How:
Prefabrication: Facetted, regular formwork boards of the same length as the height of the columns are laid out on the floor – the boards lie parallel!. A piece of fabric is cut out and placed on the boards– The fabric is stapled to the boards.
On site: Three boards are removed and holes made to fit the clamp system. Bolts are put through the 'spine' of the formwork. Distance tubes placed on bolts. The formwork is folded and overlaps on the middle – closed like a jacket. The formwork is raised and stands on its own. The spine is supported by to laths fixed to one point on the 'spine' and one on the foundation Concrete is poured and vibrated. Formwork is stripped by unbuttoning the formwork 'jacket'



Fabric - Formwork boards - Concrete

Group Photo by Jens V. Nielsen

7 / CONCRETUM 2010

Eg S S Ed

Tectonics in Building Culture - Erasmus Summer School
(4th. workshop of a series of summer schools)
Organized by ass. Professor Peter Sørenen, RDAFASA
Assignment by Anne-Mette Maneliius and Peter Sørensen

Where: Nexø, small town on the Danish island Bornholm in the Baltic Sea
Sites: 'Møbelfabrikken' and the campus of the Glass and Ceramics School of the Danish Design School

When: August 2010

Experiments

Published:
Peter Sørensen, ed., Tectonics in Building Culture: Concretum, vol. 4 (Copenhagen, Denmark: RDAFASA, Institute of Technology, 2011).
Blogposts, feauture coverage in local newspaper from pouring-day.

The Royal Danish Academy of Fine Art
School of Architecture
Institute of Architectural Technology

HOCHSCHULE LIECHTENSTEIN

Program for the summer school. Notice, it was in fact the fourth workshop

Tectonics in Building Culture III: CONCRETUM

Erasmus Intensive Program 2010 - Denmark, 17th to 28th of August 2010

Royal Academy Copenhagen, School of Architecture, Denmark (Organiser)
University of Liechtenstein, Institute of Architecture and Planning, Vaduz (Coordinator)
Academie van Bouwkunst, Amsterdam
Norwegian University of Science and Technology, Faculty of Architecture and Fine Art, Trondheim
Sint-Lucas School of Architecture, Brussels/Gent
University College Dublin, School of Architecture, Ireland
Universitat Polytècnica de Catalunya, School of Architecture of El Vallès, Barcelona
University of Ljubljana, Faculty of Architecture, Slovenia

Note: A workshop about wood was held in Norway in 2007

TECTONICS IN BUILDING CULTURE

The “Tectonics in Building Culture”-series started in Holland 2008 and opened a new field of research where tectonic aspects in buildings were materialised. To learn from bricks meant questioning our knowledge about a well-known material. Reflecting while working allowed discovering the properties of the material and finding the according building technique in a process of repeated steps. Without using any tools or mortar, a specific craftsmanship had to be cultivated which established an intensive experience that blurred the line between Building and Architecture.

TEXTILE BLOCKS

The Erasmus Intensive Program 2009 was a profound opportunity to study the tectonics of dry stone walls. Gravity and adhesion only guaranteed the structures to hold. Reflecting about a material in such a direct and physical way not only stimulated an immediate learning process but also fuelled a working period of almost two weeks at the West coast of Ireland. Working with uncut stones raised questions concerning the principles of static, the generic character of the material and the possibilities of joining without using cement.

CONCRETUM

This summer we will live and work on a small Danish Island called Nexø. After brick and dry stone our focus will be concrete. By building prototypes and structures, the project will try to animate to experience the essential principles of constructing. Dealing with concrete means to build a suitable formwork and to reinforce the conglomerate with an inner skeleton. An experimental approach will lead us to new techniques.

Participants: 4 students and 1 teacher from each University
Fee: Euro 400.00 (incl. accommodation and 75% of travelling costs)

CONCRETE- THE MATERIAL OF METAMORPHOSIS
Concrete is the material of change, of metamorphosis. Like a chameleon it appears in different disguises and in different connections. The assessments of this substance have changed over the years. In the early modern period, it has been considered a miracle material which would solve all the problems of the building industry. Later it was seen as representing the inhuman scale of large building projects and sharply criticized. (Cit. Ola Wedebrunn)

In many ways concrete is a universal material. It can take any form and shape, and it is made up of raw materials which are so commonly found that they can be extracted and produced virtually anywhere. Still concrete represents particular values that are hard to define but, at the same time, seem to be indentified with modernity in architecture by many. Concrete is predominant in our culture. Hence it is important that we appreciate this material and that we learn to understand and assess both the technology and the means of expression that go with it.

FINDING FORM, TEXTURE AND STRUCTURE
The Erasmus Intensive Program 2010 will be an opportunity to study the tectonics of concrete and testing this materials unseen potential. The workshop will try out new methods and materials of forming, in ex textile, which is very flexible and reveals new surface textures and forming possibilities.

The program will start in Copenhagen with bus excursions to new concrete architecture, but will mainly take place in locations belonging to the Danish Design School in Nexø on the beautiful Danish island, Bornholm.

The nature of Bornholm

Local delicacy

'Møbelfabrikken'

Program for the summer school.

Tectonics in Building Culture III: ”Concretum”

Erasmus Intensive Program 2010, Denmark, 17th to 28th of August 2010

Monday 16.08.2010	**Day 1** Tuesday 17.08.2010	**Day 2** Wednesday 18.08.2010	**Day 3** Thursday 19.08.2010	**Day 4** Friday 20.08.2010	**Day 5** Saturday 21.08.2010	**Day 6** Sunday 22.08.2010
	Arrival Copenhagen Accommodation: Danhostel, Copenhagen City **16.00 Welcome** Meeting at RDA School of Architecture, Holmen. (Alt.: DAC, AA) Welcome, presentation of schools and students Introduction to the workshop program in Copenhagen and Nexø. Practical questions 17.00 Reception, snacks and bar 19.00 Dinner and Copenhagen by night (Individual)	Copenhagen – Bornholm **9.00 Excursion** Busdeparture (Meeting at Danhostel) Copenhagen architecture excursion. Concrete architecture by Zaha Hadid, Jørn Utzon and new projects by BIG Architects in Ørestad. By Bus over Malmø, Sweden to Ystad (Remember Passport) 15.30 Ystad – Rønne by Ferryboat (75 min) 17.05 Bus Rønne – Nexø 18.00 Arrival and accommodation in “Møbelfabrikken”, Nexø. 19.00 Dinner (Arranged) Welcome to Nexø	Nexø 7.30 Breakfast (20 min. walk to G&K) 9.00 Welcome and introduction to “Glas og Keramikskolen” 10.00 ***Workshop W1*** *“Components”* Introduction to materials, tools and processes (AMM) Group work. Forming and casting a model component in gypsum with defined bordering surfaces. 12.00 Lunch 13.00 Moulding, casting and deforming component 16.00 An assembly of individually components Group presentation. 19.30 Danish dinner	Nexø 7.30 Breakfast Option: Morning swim 9.00 ***Workshop W2*** *“Form generation”* Project proposals for in ex. a sheltered resting place, a bus stop and a beam- or a bridge construction. Brainstorm and introduction to W2 Group competition, leading to proposals in sketches, models and text 10.00 Group work with projects and models 12.00 Lunch 13.00 Group work, documenting ideas and proposal (digital) 15.00 Analogue and digital presentation and crit of projects 19.30 Slovenian dinner	Nexø 7.30 Breakfast 9.00 ***Workshop W3:*** *“Form and structure”* Optimizing 2-3 selected projects for realization. Organizing and planning the process. Teams, workplaces, materials and site work. 12.00 Bus excursion Visit to “Bornholms Kunstmuseum” Lunch in Gudhjem (Famous for smoked herrings) (Opt. “Melstedgaard” farming museum and “Østerlars” round church) (Opt. site registration and measured drawings for foundations) 19.30 Norwegian dinner	Nexø 7.30 Breakfast **9.00 Workshop W3** Introduction to materials, tools and formwork. Statics and security. Shell, structure and component. Prefab, prefab formwork, in situ formwork. Formwork in three to four groups. Details and experiments 12.00 Lunch 13.00 Workshop Introduction to materials tools and formwork Scale models 19.30 Irish dinner

Day 7 Monday 23.08.2010	**Day 8** Tuesday 24.08.2010	**Day 9** Wednesday 25.08.2010	**Day 10** Thursday 26.08.2010	**Day 11** Friday 27.08.2010	**Day 12** Saturday 28.08.2010	Sunday 29.08.2010
Nexø 7.30 Breakfast **9.00 Workshop W3** Bus. Visit to PL Beton, concrete element factory. 11.30 Rønne. Visit and lunch (individual) 13.00 Bus to Nexø Formwork - details and experiments - shells - structures - elements - components 16.00 Group meeting Approval of projects (by community) 19.30 Lichtenstein dinner	Nexø 7.30 Breakfast **9.00 Workshop W3** Formwork Form and surface - concrete aggregats - exposed surfaces - texture and types 12.00 Lunch 13.00 Formwork and site work, foundations. 15.00 Coordinating meeting 19.30 Duch dinner	Nexø 7.30 Breakfast **9.00 Workshop W3** 12.00 Lunch 13.00 Formwork and site work 1:1 – finishing. Statics and security control. Documenting idea and work process. 15.00 Casting prefab structure and components in workshop. 15.30 Casting in forms on site 19.30 Catalan dinner	Nexø 7.30 Breakfast **9.00 Free day program** (Concrete hardening) Option 1: Bike excursion to “Balka beach” and “Dueodde” for a swim. And /or to ”Paradisbakkerne” Option 2: Roundtrip by local busses to : Hammershus”, “NaturBornholm” in Åkirkeby, an/or Bornholms Round churches Option3: Fishing from Nexø, Svaneke or Gudhjem (Boat tour?) Option 4: Day tour to Christiansø (?) 19.30 Dinner individual	Nexø 7.30 Breakfast **9.00 Workshop W3** Deforming and Documentation Prefab components. Deforming. Transportation, assembling and mounting on site In situ structures, deforming on site Cleaning up at site. Documentation of result 12.00 Lunch (On site with flags, red sausages, hotdogs, soft drinks and beer) Review with Community and local supporters. 19.30 Grill and party dinner "All Nations”	Departure day 7.30 Breakfast **Departure day** Option: 10.15 Ferry from Rønne to Ystad arr. 11.30 (Arr. Cph airport?) Option: 23.30 Ferry from Rønne to Køge arr. 6.00 and S-train to Cph. Option: 7.30 Ferry from Rønne to Sassnitz arr. 11.00 Option: …..	

PETER SØRENSEN
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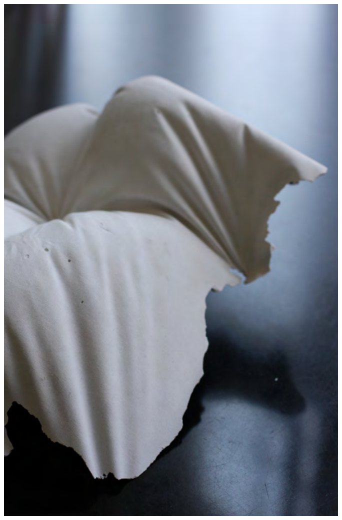
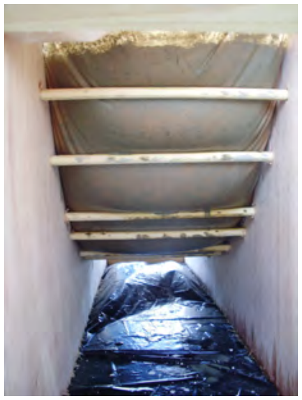


Plasterwork in hanging formwork

Working with plaster

Sequence of restraint impactos with the same 'stretch cardboard net'

Concrete tests, 1:2



Tectonics in building culture: Concrete

'Tectonics in building culture' is a field of research, where tectonic aspects of a selected material related to local building culture and innovation is studied. Four building materials have been studied: 'Wood' in Norway 2007, 'Brickwork' in the Netherlands 2008, 'Textile Blocks' in Ireland 2009 and last 'Concretum', in Denmark 2010. The Erasmus workshops are organized in collaboration between the hosting universities and the coordinating University of Liechtenstein and are supported by the European Community.

Tectonic studies and material experiments are based on a succession of theoretical and practical group works. The workshops confront students and teachers with physical laws of a seemingly well-known material, and preliminary studies and excursions provide the related cultural background for materiality and tectonics. The workshops give an intensive, academic, cross-cultural experience that breaks down barriers between idea, thinking and making.

The Erasmus IP 2010 workshop "Concretum" took place in Nexø, Bornholm. The program aimed to study concrete's unseen potentials by the use of textile as a most flexible form material. 45 very dedicated students and teachers from eight European Architect schools took part and realized four full-scale projects on site;

A BRIDGE,
A WALL,
SITTING SCULPTURES AND
STORE PLACES FOR FIREWOOD.

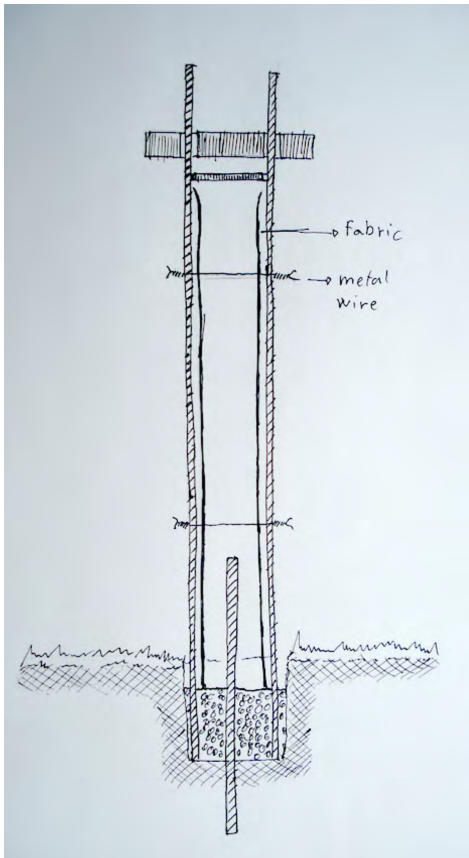
BRIDGE

Site:Møbelfabrikken, Nexø

Sculptural bridge across a little stream in the middle of 'Møbelfabrikken'. Fabric is not dominant in the structural formwork principle but the tensioned and twisted shape was derived from previous plastermodels.

The workshop ran out of geotextile so tarp was used as formwork membrane. The bridge was cast 'on stilts' (firewood) in situ. Afterwards the firewood was removed and the bridge placed

Images: Balazs Jelinek



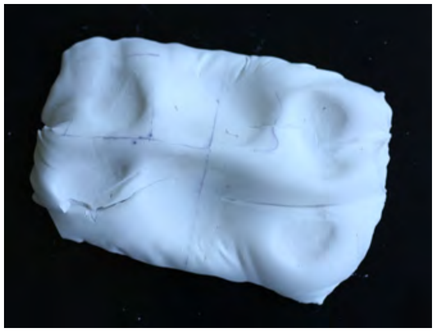
WALL

Møbelfabrikken, Nexø

Several principles for a sculpture was proposed. In the end a low wall was constructed using iron bars as frame restraint method. Bars were furthermore tied with metal wire.

Series of plaster casts.

Lines on plaster model indicate the shared section where the large surface is divided into smaller units



S

SITTING SCULPTURES

Site: Danish School of Design, School of Glass and Ceramics, Nexø

Initial experimentation with plaster contained the notion of a series of casts influencing each other. The 'sitting sculpture' was first intended as a massive concrete landscape but altered to become four sculptural units that can be repositioned and fit together along certain points along the the edges. The group managed to develop an effective procedure for the serial construction of the four different concrete shells

Shells cast and reinforced upside down in suspended fabric form

WOOD SHELTER

Site: Danish School of Design, School of Glass and Ceramics, Nexø.

The school has several firing kilns outdoors and use a lot of firing wood. The existing storage place for wood, however cuts off the view and access to an old garden with apple trees. The student group suggested a conceptual approach to the expressed need for a shelter.

Eg

FABRIC FORMWORK

By Anne-Mette Manelius

Sheets of woven textiles can be used as flexible, lightweight formwork for concrete structures. The relevance of developing fabric formwork touches upon two fields of evolution: that of concrete construction which has continued for millennia and that of textiles with an even longer history – recently of an almost revolutionary character.

Concrete is the most widely used building material worldwide. At the same time developments in digital design and engineering tools have changed the way architecture is conceived and calculated. However, methods for constructing concrete structures haven't developed at the same pace; the architectural vocabulary of concrete can be developed with regards to form, structure and surface in order to exploit the potentials of the so-called liquid stone.

Textile technologies have undergone an immense technical development in which existing, previously crafts based production techniques are combined with new or alternative material fibers and scales in order to produce flexible, strong and light fabrics with new material properties. As such, textiles are finding their way into construction at different scales. With regards to formwork it could be asserted that the considerate combination of textile technologies used as formwork for concrete may participate in unfolding potentials for concrete and extend its existing architectural vocabulary.

There are two technical characteristics about fabrics, which are essential when used as concrete formwork. The first technical aspect is that fabrics act in tension under the hydrostatic pressure of wet concrete. This dynamics results in a bulging surface between points of restraint. The deflections are all catenary curves, which indicate that the forces are spread evenly all along the fabric surface. This means that fabric is an effective formwork material in transferring the pressure upon the inside to the entire surface. That's why so little fabric can hold heavy amounts of concrete.

The second technical aspect deals with the porosity of woven fabrics. Excess air and water go through the formwork membrane as the concrete is poured – the fabric appears to be sweating - it results in fewer blowholes and a higher level of cement compared to water – the so-called water-cement ratio is low. A smooth, tight concrete surface is desirable because it is stronger and less likely to crack.

A third, formal aspect is the result of the two technical characteristics. The direct formal consequence at stake in fabric forming seems the most architecturally intriguing. Concrete will always show the imprint of the surface structure and connections of the applied formwork material, yet this is particularly expressed using fabrics: the form, size and placement of restraining device, and the detailed weave of the chosen fabric will show on the form and surface of concrete. This reveals the narrative of architectural becoming embedded in concrete.

Stereogenés

With kind assistance of Greek author Iosif Alygizakis, I've attempted to coin a word to embrace this duality in, on one side, the experienced, sensed qualities of a cured concrete structure as material and, on the other, those almost metaphysical traces of becoming that may be the most poetic feature of concrete! Stereogenés is Greek. It consists of two words, the adjectives stereo, solid and genés, derived from the verb ginomai, procedure of becoming. Cured concrete then is stereogeneous, solid but, as the word indicates, it obviously has become so through a number of processes from a liquid state.

These procedures to becoming concrete include processes of chemistry and statics; the chemical processes within the concrete mix when cement reacts to water; and the formwork statics when the form is filled with concrete. Both are results of human actions: the former through the design of the concrete mix; the latter through the design and construction of the formwork tectonics.

Concrete construction can be seen as a series of carefully conceived and executed processes that inform concrete architecture. One can look at the potentials for the future implementation of fabric formwork in several of them, namely in the design and production of fabrics; of 'haute couture' or mass produced fabric forms or concrete elements.

Concrete is nothing without its process – yet is definitely something during its use, and something more than merely a space defining structure. The further unfolding of Stereogeneity will attempt to create a holistic view of concrete as both process and material.

Anne-Mette Manelius, "Fabric Formwork," in *Tectonics in Building Culture: Concretum*, ed. Peter Sørensen, vol. 4. (Copenhagen, Denmark: RDAFA, Institute of Architectural Technology, 2011), 16-19.

FABRIC PROPERTIES EXPLORED IN THE WORKSHOP

Four concrete pieces in the Bornholm town of Nexø show potentials of fabric formwork. Each piece was designed for a specific Nexø location and each formwork structure explores a fabric property in a different way leading to concrete structure that could not have been cast in any other material than fabric.

Tensioned fabric (Elements)
One workshop group produced four familiar but unique concrete shells to function as sculptural furniture units for the garden of the design school. Double curved elements share matching curved geometric shapes along the edges, which allow students to position elements anew and create variations of a sturdy furniture topology. The formwork for the shells consists of fabric stretched out between sides of a plywood frame with curved edges easily cut and in 2d.

Embracing (Shelter)
One workshop group created a simple and effective formwork solution for a sculptural wood shelter for the outdoor kilns at the design school. Fabric acts as an embracing agent – a formwork jacket is closed loosely around a tight cluster of firewood and concrete filled the gap between wood and fabric to create a tubular container fitted perfectly to the intended inhabitant.

Embraced (Wall)
A curved wall was produced on site at Møbelfabrikken in fabric restrained by rows of reinforcement iron connected by steel wire. The structure is high enough to allow the inhabitants of the hostel and office building to have a coffee break protected by the wind – yet low enough to look over.
The structure caused challenges: how to finish the pour when the formwork can be folded – and how to scale findings from previous test pours? The structure revealed a fragile part of the formwork technology: when the concrete is compacted and has set it will be damaged from further vibration. Traditional rigid formwork protects the vulnerable wet concrete here – and flexible formwork should be let be.

Design (Bridge)
The design of a bridge or passage across a below ground stream was initiated by playing with fabric and plaster to create beautiful and statically effective double curved tensioned structures. The diagonal shape opened alternative ways of designing the passage itself and the final piece was cast on site with an intricate design for stripping the supporting formwork afterwards. The final, twisted bridge was cast in a combination of wood and a tarp membrane.

Anne-Mette Manelius, "Fabric Explored," in Tectonics in Building Culture: Concretum, ed. Peter Sørensen, vol. 4. (Copenhagen, Denmark: RDAFA, Institute of Architectural Technology, 2011), 25.

Udfordringen i eksperimentet bliver meget konkret og håndgribelig – alle må hjælpe til med skovle, spande, hænder og fødder for at få betonen til at føje sig. Foto: Allan Rieck

Hård beton i nye bløde rammer

NEXØ

Af Elisabeth Krogh

En betonkanon er ikke et hverdagssyn på Nexøs to kreative virksomheder, iværksætterhuset Møbelfabrikken samt Designskolen på Stenbrudsvej. Men onsdag rullede en stor tung lastbil med flydende beton ind begge steder og afleverede sin last af flydende beton.

For de fleste er beton et materiale, der er så fast og anvendes i så faste former, at det »at være beton-agtig« sidestilles med at være firkantet og ufleksibel på alle måder. Men i denne uge har en gruppe studerende fra otte forskellige europæiske arkitektskoler sat hinanden stævne i Nexø – og den fælles udfordring er at vise, at beton ikke kun behøver at anvendes til firkantede trapper, gulve og mure. De arkitektstuderende har sat sig for at ville udfordre betonen og forme det kompakte materiale efter deres egne snørklede ønsker.

– Det handler om, hvordan man kan tænke materialet beton på en ny måde. Normalt ser man kun beton i meget firkantede rammer. Vi ville udfordre, hvad beton kan, forklarer Anne-Mette Manelius, Kunstakademiets Arkitektskole København.

»Jeg synes, det er rigtig fantastisk – også selv om vi måtte bruge skovle og hænder«

Hun står sammen med lektor Peter Sørensen for arrangementet, hvor 45 arkitekter og -studerende fra otte forskellige europæiske arkitektskoler er på en sommerworkshop i Nexø.

Temaet for workshoppen er at eksperimentere med at støbe beton i tekstil – hvilket er nytænkning og kaldes tekstilforskalling.

I løbet af ugen har de studerende opbygget støbeforme af forskellige tekstilmaterialer – møbelstof, presenning og vævet plastikstof. Det er materialer, man ikke normalt tænker på som ramme for en betonkonstruktion.

I de lette materialer var der i ugens løb gjort klar til onsdag at støbe en smukt svunget bro over bækken i Møbelfabrikkens gårdhave – en fire meter lang stående bølgende skulptur samme sted. På Designskolen var der gjort klar til at støbe blandt andet tynde skaller af beton ved at lægge betonen ud i rammer med fastspændt stof.

Oh no!

Da den tunge betonkanon rullede op, og betonchauffør Flemming Rasmussen trak transportbåndet ud og hen til de studerendes spinkle konstruktion i Møbelfabrikkens gårdhave, var spændingen derfor stor hos deltagerne. Ville konstruktionen af de meget lette materialer – og endda i lodret form – kunne holde betonen på plads?

Også Flemming Rasmussen kløede sig lidt i håret over den usædvanlige opgave, men betonkanonen blev tændt og alle var klar.

Pludselig vælter betonen frem ad transportbåndet og ned over den hjemmekonstruerede tragt, de arkitektstuderende har bygget. Der råbes på en lang række sprog og hænder, skovle og små stykker træ bliver taget i brug for at få betonen på rette vej – ned i konstruktionen af metaldragere og det tynde vævede plastikstof, der skal holde den flydende beton på plads.

»Oh« og »no« lyder det på både engelsk, spansk og dansk, for idéen med at lade betonen flyde gennem den hjemmelavede tragt, fungerer ikke.

Udfordringen i eksperimentet bliver meget konkret og håndgribelig – alle må hjælpe til med skovle, spande, hænder og fødder for at få betonen til at føje sig.

I sidste ende lykkes det, og betonen lade sig presse sammen i den meget anderledes og fleksible »støbeform«.

Først fredag fjernes støbeformene, så værkerne kan ses, men allerede nu, har eksperimenterne vist, at beton kan bruges langt mere fleksibelt, end der er tradition for.

– Man kan ret enkelt lave nogle former, man selv bestemmer. Man er ikke begrænset af fast form. I dette forsøg er vi kun begrænset af tekstilet og metalpindene, forklarer Anne-Mette Manelius efter gårsdagens forsøg.

Hun er arkitekt og i gang med en phd om tekstilforskalling.

Støbeøl

Stemningen var høj, da betonen var på plads i de utraditionelle støbeforme af forskellige bløde stoffer som presenning og vævet plastik.

– Vi har skabt både en bro og en stående skulptur. Jeg synes, det er rigtig fantastisk – også selv om vi måtte bruge skovle og hænder for at lave muren, siger Anne-Mette Manelius.

Og bagefter var der støbe-øl fra kassen, der havde stået til afkøling i bækken, mens støbearbejdet var i gang.

Betonen til eksperimenterne var sponsoreret af NCC, Bornholms Betonværk. Chauffør Flemming Rasmussen leverede omkring halvandet ton beton til de studerendes eksperimenter.

Meget af det tunge, flydende materiale blev der arbejdet videre med ved håndkraft – med en deadline – for beton størkner i løbet af nogle få timer.

En svunget betonbro skal gå over bækken i Møbelfabrikkens gårdhave. Foto: Allan Rieck

SOMMERSKOLEN

- Sommerskolen er en årlig workshop for arkitekter og arkitektstuderende fra universiteter i Europa.
- I år deltager 45 fra bl.a. Amsterdam, Brussel, Irland, Slovenien og Trondheim i sommerskolen i Nexø. Gruppen bor under opholdet på Møbelfabrikkens hostel, og arbejdet har foregået i og omkring værkstederne på Møbelfabrikken og Designskolen, og fra morgen til aften har der været livlig aktivitet.
- Værtskabet for sommerskolen om byggematerialer og bygningskultur går på skift blandt de deltagende nationer og i år var det Danmarks tur og arrangørerne havde valgt at placere arrangementet i Nexø på Bornholm.
- Udover de faglige aktiviteter har der også været tid til socialt samvær – blandt andet at forsøge at overgå hinanden i »nationale middage« – så opholdet har karakter af en lille højskole for deltagerne.

ck

På Designskolen støbes bl.a. tynde skaller af beton ved at lægge betonen ud i rammer med fastspændt stof. Foto: Elisabeth Krogh

NEXØ·SVANEKE

Fra en anden workshop, hvor stofposer er støbeformen for beton. Foto: Anne-Mette Manelius

Kan beton være blødt ?

Af Elisabeth Krogh

Møbelfabrikken i Nexø blev i sidste uge indtaget af 40 internationale arkitektstuderende sammen med deres lærere fra otte forskellige europæiske arkitektskoler. I perioden 19. til 28. august opholder de mange arkitektstuderende og lærere sig i Nexø. Møbelfabrikken er i år base for en årlig sommerskole om byggematerialer og bygningskultur, hvis værtskab går på skift blandt de deltagende nationer – og i år er turen kommet til Danmark – og sommerskolen holdes så i Nexø på Bornholm.

Sommerskolens tema er spørgsmålet: Kan beton være blødt, og hvordan kan man støbe tung beton i lette tekstiler? Et særligt fokus for betonworkshoppen bliver, at støbeformene til betonstøbningen udgøres af tekstiler. Tekstilforskalling er en helt ny teknologi, hvor støbeformen til betonkonstruktioner er så let, at man kan tage den med i en sportstaske – sommerskolen medbragte f.eks. en rulle af det særlige stof med på færgen fra Ystad, fortæller Anne-Mette Manelius, som er arkitekt og erhvervsPhD studerende/Industrial PhD Student på Kunstakademiets Arkitektskole, som i år står for sommerskolen.

De arkitektstuderende vil både arbejde på Møbelfabrikken og på Designskolen i Nexø (der før hed Glas- og Keramikskolen).

I løbet af de næste ni dage skal der eksperimenteres og arbejdes intenst med modeller af gips og beton. Designskolen og Møbelfabrikken giver husly til eksperimenterne, hvor den særlige betonteknik kan afprøves for første gang i Danmark – i hvert fald udenfor Arkitektskolens forskermiljø, hvor en af sommerskolens arrangører skriver PhD om emnet. Alle undersøgelserne kulminerer i denne uge, hvor de færdige, store tekstilstøbeforme skal fyldes, og en stor blandebil ankommer med beton sponseret af NCC, Bornholms Betonværk.

Sommerskolen er kommet til Nexø, fordi Møbelfabrikken har en unik kombination af hostel og værkstedsfaciliteter, som er en perfekt ramme for sommerskolen. Udover det faglige indhold i sommerskolen er det sociale møde mellem de internationale studerende ligeså vigtigt. Og så er det for de fleste det første møde med Bornholm, hvor de tilbringer de sidste ugers sommerferie, inden studierne atter kræver fuld opmærksomhed tilbage på arkitektskolerne.

"Hard Concrete In New Soft Frames." Newspaper article from the local island newspaper. Live report from the pour day, including an interview with the local truck driver

Local newspaper article about the workshop

8 / TEK1 2011 / BENCH

H Ed Ed Ed Q S Ed O H Ed O Ed

TEK1 is a mandatory course in building technology for the first-year students of architecture

Where: RDAFASA
When: March 2011

Experiments

Published:
Blogpost

TEK1 2011, March 10-18,
Concrete Workshop
Translation of the assignment

Participants
50 architecture students, RDAFA
35 architectural engineering students, DTU (Danish Technical University)
The objective of the material workshop is to become familiar as well as challenge one of the World's most used building materials, concrete. A particular focus of the workshop is fabric formwork.

The ambitions for the workshop are high and time is scarce – challenges and solutions in the work emerge through making. First in the work with scale models in plaster and later subsequently during the construction of 1:1 formwork structures.

Assignment – a concrete bench for the quay
Functionally a bench is a piece of furniture with a height of circa 45 cm. is it a bench for engaging in conversation, or to enjoy the view?
Structurally, a bench is often a suspension, at a certain height, between supports. It can also have a sculptural appearance.

Criteria in design and construction
Functionality and aesthetics
Optimized/minimized use of concrete
Challenging use of formwork materials
Logistics: Transportation, filling (concreting) and stripping of formwork structures.

Available materials
Textile
6mm and 20 mm plywood boards
Lats, ca 6x8cm
Reinforcement iron
Screws and brackets
Form-ties

Fabric formwork and form-ties
A focus of the workshop is an alternative formwork material, textiles-

The formwork consists of a structural frame, which suspends or supports the sheet of fabrice, and socalled form-ties hat restrain the fabric.

A number of questions should be considered. What are the specific properties and characteristics of the formwork materials of the workshop – Using these characteristics, what can be achieved with concrete, which cannot be achieved in other materials?
How to build statically optimized concrete structures or in a simple fashion make a complex geometries, or achieve surfaces that show the liquid origins of fresh concrete?

Process: Storyboard
In order to achieve a mutual overview, each group draws a storyboard, where the steps as well as construction principles and details are drawn and explained.
Considerations include:
How do the formwork materials meet; where and how is reinforcement placed in the formwork structure; in which direction is the formwork constructed and filled, sideways, upside down or?

Concrete arrives in a big truck with a chute or a pump. It will only be on the quay for a short time to fill all the formwork structures. How will the formwork be filled and how do you assure that the formwork reaches all the corners the formwork (compaction); last but not least, how can you dismantle the formwork structure when the concrete has hardened and avoid screws cast into the concrete or placed on the inside of the formwork.

Report
An important part of the assignment is a 10-page group report. It consists of drawings, sketches, and photos and is handed in at the end of the workshop.
The list of demands sound comprehensive but are meant as a shortlist.

The report is a sort of reflexion of your experimental work. How did you approach it and what did you learn in regard to the materials and the processes.

The report includes the following:
Title of the bench as well as the names of the group members.

Which questions does the group pose: to fabric formwork, to concrete, a bench??
How is the posed question challenges and answered throughout the workshop?
Each part of the assignment is described – what can be improved for the next step?
Include the storyboard, which descirbes the construction and concreting, and supplement with isometrics, sections and photos of especially important details of the formwork structures.

Reinforcement – drawings and arguments for the placement.
How much concrete should be ordered- show the calculations of the estimated volume/use of concrete.

Select photos of particularly interesting or surprising details from the formwork as well as the finished concrete bench.
What went well, and less well – what could be improved – what did you learn?

English

TEK1 workshop, beton – revideret program 2011-03-04, AEM
KA: kort og find vej: www.karch.dk/dk/Menu/Om+skolen/Find+vej/Find+vej
DTU kort og find vej: http://www.dtu.dk/upload/administrationen%20-%20101/vejviser/dtu_kort_jan_2011.pdf

Week I

Mandag d. 7. marts	*Tirsdag d. 8. marts*	*Onsdag d. 9. marts*	*Torsdag d. 10. marts*	*Fredag d. 11. marts*
Formiddag: Forelæsninger KA, aud 2 Kl 10-11: Beton som arkitektonisk materiale / flydende sten	Formiddag: Forelæsninger KA, aud 2 Kl. 9-11. Beton som proces, beton som konstruktion	Formiddag: Forelæsninger KA	**9-11: DTU Speed-Gennemgang. 11.30-12.30: diskussion, opsummering, introduktion til næste fase Det foregår på dtu**	**1:1 arbejde DTU, Bygning 117**
Morning Course lectures	Morning Course lectures	Morning Course lectures	Speed critique and introduction to construction phase	1:1 construction
Eftermiddag: KA, aud Y8 Brainstorm og gennemgang	**Eftermiddag: KA aud Y8 Principmodel 1:5 i gips**	**Eftermiddag KA, aud Y8 Story-board for forskallingens produktionsproces,**	**Eftermiddag: DTU ,117 1:1 arbejde DTU**	**1:1 arbejde DTU, 117**
Afternoon Brainstorm and crit.	Afternoon Principle model 1:5 plaster	Afternoon Storyboard and drawings	1:1 construction	1:1 construction

Week II

Mandag d. 14. marts	*Tirsdag d. 15. marts*	*Onsdag d. 16. marts*	*Torsdag d. 17. marts*	*Fredag d. 18. marts*
Formiddag: Flytning af forskalling fra DTU til KA, samt sidste oprydning	**kl10: KA Udstøbning af betonemner på kajen Dtu, kan ikke**	Formiddag: Forelæsninger KA	Formiddag: Forelæsninger KA	Eftermiddag: Fælles kursus gennemgang på KA
Moving formwork	Pour day	Course lectures	Course lectures	'topping-out ceremony' with all material workshops
Eftermiddag: KA. klargøring og nivellering af støbeforme , samt udarbejdelse af rapport	**Eftermiddag: udarbejdelse af rapport**	**Eftermiddag KA: Afforskalling samt rapportskrivning Dtu deltager**	**Eftermiddag: Intern gennemgang på KA**	KA: '*rejsegilde*' på kajen
Last finishes on formwork structures on the quay	Finish reports	Stripping formwork and clean up	Stripping formwork and clean up Hand in reports	

8.1 BENCH FOR THREE H

RDAFASA Students: Tuva Aune Larsen, David Hugo Cabo, Lasse Skafte, Nikola Antonijevic; DTU: Ida Sørensen, Mikkel Christensen, Chalotte Larsen.

What:

A bench for three people having a conversation. The aim was to create an upholstered look for the seat. Different formwork principles and casting directions were tested in the 1:5 plaster model.

How:

The piece contains a number of different techniques:
To obtain the bulging surface of the seat, the formwork was constructed to be cast upside down and restrained with form-ties.
The three legs of the bench were prepared as columns. Notice that the shape of the columns were formed by fabric tensioned between ellipse-shaped holes that were placed orthogonally in the top vs the bottom. The seam of the column was made by rolling and stitching, a technique deviced by Mark West (see 4/ Vermont Wall)

8.2 DATE BENCH Ed

RDAFASA students
RDAFA: Elisabeth Gellein, Erika Østman, Jens Berglien; DTU: Lærke Cecilie Bjerre, Mia Halberg Homann, Helle Vedø Jeppesen, Karina Skjærli Hansen

What:
A comfortable bench for two. the use of fabric formwork allowed for a free-formed section.
Two plaster models were cast, one in wire cut EPS and one in fabric formwork, experiences were made from both casts.

How:
The bench was cast sideways and constructed as a wall. Fabric was suspended in a rig and constrained by multiple vertical laths. One side of the formwork (for the seat) was further constrained by the placement of chicken wire between geo-textile and laths. The underside of the seat was allowed to bulge between laths.

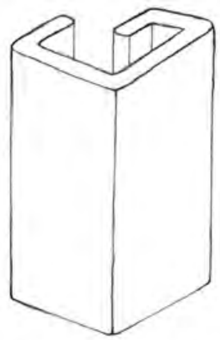
8.3 G BENCH

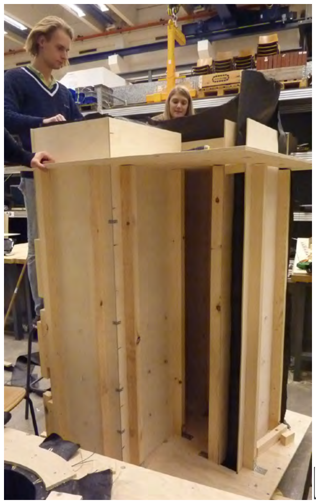
RDAFASA students: Sofie Overgaard, Victor Giødesen Thystrup, Astrid Blichfeldt, Sophie Daugaard Andersen. DTU: Tina Dahl, Tim Kjærsgaard

What:
A G-shaped seating module with flat surfaces and two seating hights. The initial idea was a curved seat. A plaster model was cast using a composite wood-textile in which the fabric acted as embracing agent. However, constraining issues as well as issues with achieving the curvatures were not resolved in this model, and hence the principle was simplified.

How: The formwork principle is rigid formwork lined inside with fabric. The bench is cast 'sideways' like a wall.





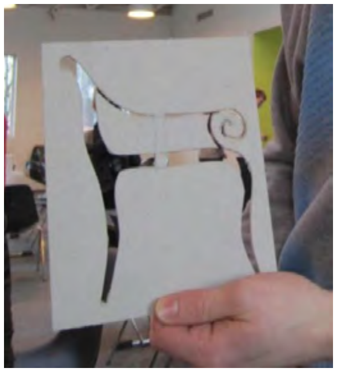



8.4 COPENHAGEN BENCH

RDAFASA students: Kristine Smette and Helge Lau Mortensen; DTU: Rikke Opstrup Hansen, Allan Ulrick Døj, and Malin Therese Josefsen.

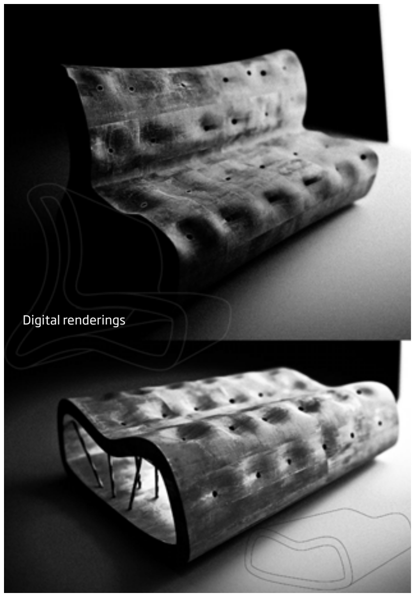
What:
The bench was a paraphrase of the so-called Copenhagen Bench, which has cast-iron sides and wooden seat and backrest. Fabric, rigid laths and plywood were used to form the seat, which was suspended between two sides. Elements of the complex formwork principle were tested in plaster. Students devised a stencil frame technique to create a relief shaped as the characteristic profile.

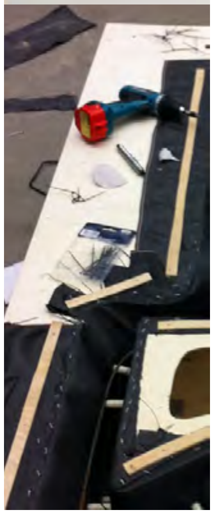
How: The formwork principle was cast upside down. The seat was 'molded' over a contour, and form-ties would were used as water drains. A newspaper was placed on the seat to leave an imprint. Special details were devised where textile met plywood.

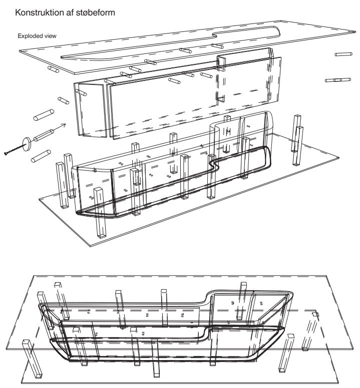













8.5 KOMPAKT

Q

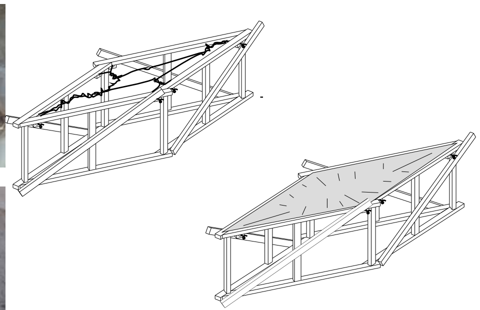
RDAFASA students: Kia Lundorff, David Botofte Henriksen, and Selma Rguez; DTU: Thomas Rerkov, and Tina Harksen.

What:

The group devised a clear principle with a rigid/flat interior and a 'pillow-like' exterior and tested their design in 3D models before settling on a design. They aimed for a simple principle in order to work out the construction details.

How:

The bench was cast sideways like a wall. An interior rigid core was created, and holes were made 'at random' for the application of form-ties. Fabric was suspended in a rig with a cutout. Considering the well-carried out design, one detail to improve was the edge condition, where sharp edges were the result of an opening that may have been too wide.



8.6 RHOMBUS

S

RDAFASA students:
Alexander Vedel Ottensten, Leonard Thor-Oscar Fagander, Lotte Astrup Mikkelsen, and Guro Hjelle; DTU-student: Maria Vallentin

What:

The group was inspired by a beanbag chair. Fabric suspended across a frame was to be molded into shape. The initial concept was tested in plaster cast in thin fabric. For the plaster model it was possible to create a constraining rope system to control bulges and create seats and a back. An initial square shape was modified to a rhombus shape to reduce the volume while maintaining the seating concept.

How:

A rig was constructed as a rhombus shape, and geotextile was attached to the rig. Rope was used as restraint. The rope was either too loose or too elastic, or the textile was stiffer than anticipated. Either way, the sculptural effect from the constraining principle failed to occur.

8.7 HAM (ROTATION)

RDAFASA students: Emre Üsüdür, Esben Wisbech, and Mathias Rode; DTU-students: Benjamin Bech Andersen, Casper Haugaard, and Louise Haack Lykke

What:
Rather than designing a bench, the group devised a formwork principle which they explored as a sculptural object. The formwork principle consisted of a series of identical frames. The principle exploited the relationship between rigid frame members and the flexible fabric, as the frames were angled from a vertical position to a horizontal.
The principle was tested in a plaster model.

How:
For the full-scale formwork structure, form-ties were added. The form-tie tubes did not reflect the dimensions needed to serve as ties, and instead they became highly ornamental.

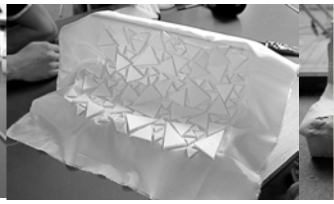


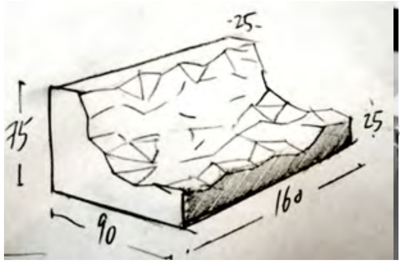


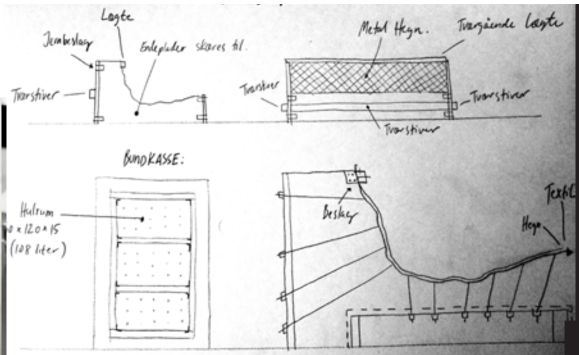
8.8 898 (SOFA)

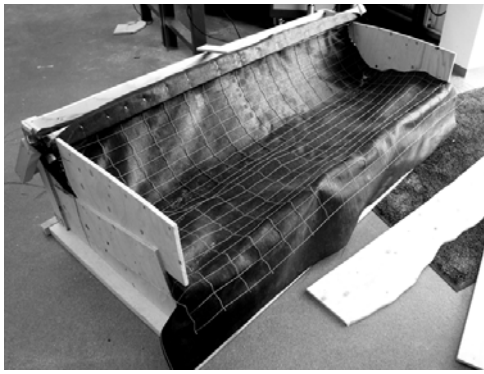
RDAFASA Students: Cisse Bomholt, Philip Messmann, Michael Sivertsen, Maja Kozak Dehlin, and Amanda Lilholt; DTU: Mathias Rasmussen, Søren Rosendahl Svare, Kenni Bruun Rasmussen.

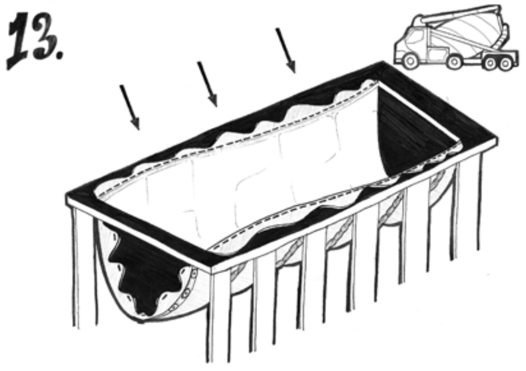
What:
The aim was to exploit fabric to make a seat that could only be cast in fabric. The group was inspired by the expression of the Seal (2.5) and the Net Wall (6.3), which were still standing on the RDAFA campus. The principle was to create a seat 'cut' out of a solid block. Triangular disks were used for the plaster model instead of restraints. This resulted in an undesirable 'muffin' shape, and it was decided to add restraints to the full-scale piece.
How:
Due to the anticipated weight, 898 kg, and to avoid handling, the piece was cast upright and filled from the back. A box was constructed with sides made up of sheets of plywood. The contour was cut with irregular/angular edges. In order to use less concrete and to tie the restraint net, an interior core was constructed and fastened. An intrinsic restraint system was devised to tie a garden fence down and ensure bulges despite the low formwork pressure on the top surface of the formwork. An improvement to the sculptural 'sofa' would be to include a system for water drainage, either through controlled surfaces or drain holes.

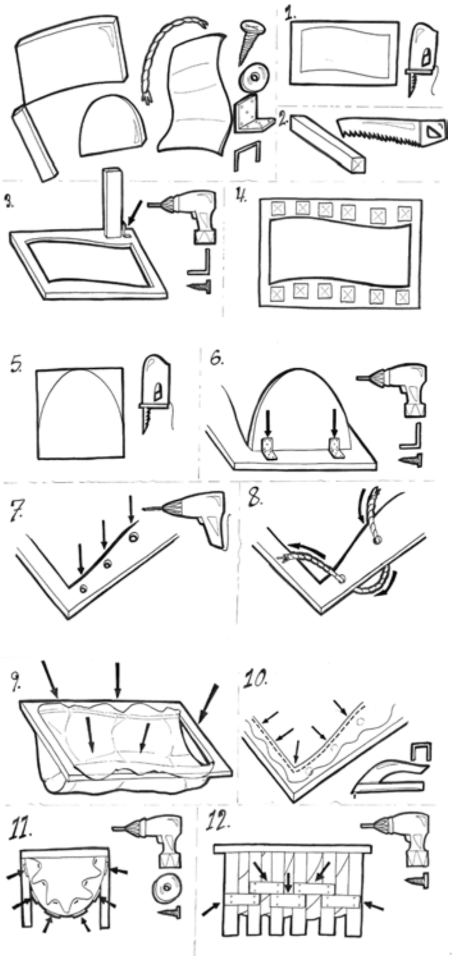











8.9 ROPE

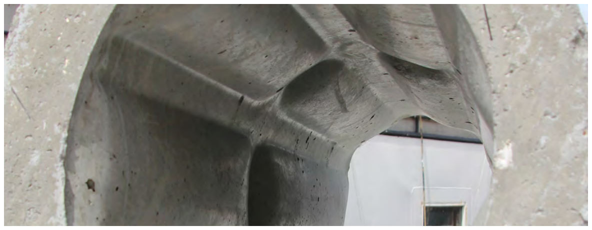
RDAFASA students: Anders Nottveit, Hafsteinn Ævar Jóhannsson, and Lou Charrier; DTU: Simon Andreas Hansen, Thorbjørn Jørgensen, and Lasse Høg.

What:

The team was inspired by the maritime context of the workshop quay and especially by sturdy rope. The plaster model revealed several inherent challenges, and the group dismissed the original idea and instead devised several new 'maritime' concepts such as the 'water flow sculpture,' a cubist fish, and a very rigid generic bench. These concepts were not tested. Finally, the team returned to the initial idea and simplified the principle.

How:

The object was cast upside down. Rope served as the constraint for a suspended sheet of fabric. The ends of the bench were made of curved coated plywood. The slightly curved shape of the seat was cut out of a sheet of plywood, and a rig was devised with laths. Fabric was suspended, and a system of hanging constraining rope 'spiraled' along the shape. To minimize the volume, 'stuffing' made of EPS wrapped in plastic was held down by bricks (found on the quay).



8.10 CLOVERLEAF

RDAFASA students: Alva Altgård, Symra Joner Andbo, and Helga Hallgrimsdottir; DTU students: Rasmus Von Wurstemberger Nielsen, Marie Rugholm Nielsen, and Andreas Klestrup Hansen

What:

120 cm long seating sculpture. The sculptural ambition for the bench was to create a simple and organic form to exploit the fabric as formwork. The bench was a hollow structure obtained by placing a rigid core in the middle of the formwork. The three 'leaves' of the clover are separated by vertical restraint poles. The initial plaster model was successful, but severe leakage showed weak points in the formwork structure.

How:

The bench was cast as three connected columns. The inner core was constructed with laths between contours cut out of plywood. Vinyl flooring was used to cover the core and obtain a smooth inner surface. The exterior form was constructed by means of suspended fabric in a rig. Three glass fiber poles worked as constraints, connected at the top and bottom. The formwork became sturdy but very heavy. The final concrete showed an imprint from a section of the rig.

8.11 TONGUE

O

RDAFASA students: Frida Maureen Borgen Hultberg, Saga Rudehill Olcén, and Carl Theodor Sachs; DTU students: Therese, Frederic, and Rasmus (last names were not included in the report)

What:
The aim was to make a light bench arching out from a heavy foundation. Initial ideas involved very slender shapes. A fabric tube was cast in a U-shape, but the plaster models of these first principles were undesirably bulky and heavy. The principle called for a different bendable sheet material or a different concreting technique. The group instead changed its ambition from the slender shape to a more radical approach to the making of the formwork.

How:
The sculptural object was cast upright on a falsework system of ribs. A formwork bag was assembled over the frame, and all the details were sewn with metal wire. The group incorporated the pour in the closure system of the formwork, which almost resembled a body bag. The formwork bag was open at the beginning of the pour and was literally tied up as the form was filled. Details on the concrete surface show the stitches from the closure of the bag. A wonderfully disturbing piece!





8.12 CRUSHED WAVE

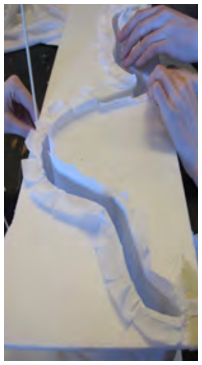
Ed

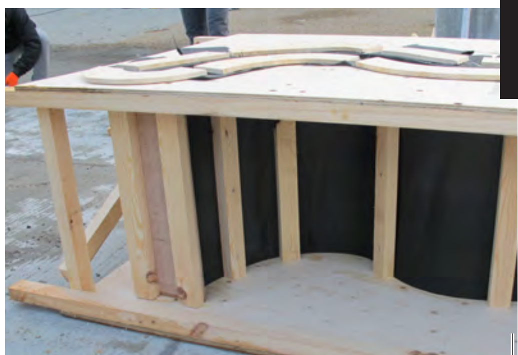
RDAFASA students: Philip Sjöberg, Petrine Eikeland, and Emil Ottar Riise; DTU students: Anders Kirkegaard, Michael Nielsen, and Cecilie Brandt-Olsen

What:
The group designed a long-spanning curved structure. The formwork principle was to cast the bench sideways like a wall. Much effort was put into designing the most desirable shape. An initial plaster model was cast in fabric and reassured the group that their principle could sustain full scale construction.

How:
Laths were cut and placed between plywood sheets along the cutout contour of the seat. Fabric was suspended in this rig. No restraints were used, as the number of secure laths appeared sufficient in relation to the 60 cm height of the pour. Unfortunately, the night following the pour was very cold (zero degrees Celsius = freezing), the formwork was only minimally protected with thermal mats, stripping time was chaotic, and time was scarce. In short, the piece was handled before the concrete had set sufficiently, and the structure broke. The rest of the student groups learned from this experience and waited one more day to turn their casts.



9 / SELECTED TEXTS

The Role Of Material Evidence In Fabric Formwork For Concrete
Do You Speak Concrete?
Formwork Tectonics – Rhetorical and Instrumental Roles in Fabric Formwork For Concrete
Experimental Data – Fabric-Formed Concrete as Material and Process
The Role of Physical Models

ARTICLE

Manelius, Anne-Mette. "Do You Speak Concrete?", no. 8. Arkitekten (August 2011): 69.

ARKITEKTEN AUGUST 2011

Moderne tekstilteknologier gør det muligt at udnytte lette, fleksible tekstilers egenskaber i støbeforme til beton (et byggemateriale der er kendt siden antikkens Rom), og tekstilforskalling er emnet for et erhvervs-ph.d.-projekt nær sin afslutning. Heri besvares det bl.a., hvad det betyder for betons „stereogenitet", at tekstil indgår i et udvidet arkitektonisk ordforråd for beton.

DO YOU SPEAK CONCRETE?

Af Anne-Mette Manelius

Stereogenitet kommer af de græske ord 'genés' (der betyder 'blive til') og 'stereos' ('fast'). Jeg har dannet ordet til at beskrive den solide beton, som den fremtræder efter en række tilblivelsesprocesser. Stereogenitet angiver betons dualitet som både materialitet og proces. Ordet er mere nuanceret end blot 'det støbte'.

I det følgende kommer jeg ind på nogle af de elementer, som er centrale for arbejdet med tekstilforskalling:

Rammen, *formbinderen* og *tekstilet* er hovedelementer i tekstilforskalling og optræder på forskellige strukturelle og betydningsgivende niveauer. En *stencilramme* er en kassette med et udskåret hul, hvorigennem tekstilet poser ud under den flydende betons tryk. Dette giver mulighed for at lave materialeoptimerede T-bjælker, som bl.a. ingeniør og ph.d. Daniel Lee fra University of Edinburgh (nu adjunkt på Kunstakademiets Arkitektskole) har vist det.

Den *faste søm* er et aftryk af tekstilets samling. Tekstilforskalling kan principielt skræddersys, men for at give sømmen styrke samt ved armering og montage kan en søm i tekstilforskalling fx fremstå som en stor klampe. Sømmens udformning får således en ganske omfattende formel konsekvens for betonens stereogenitet.

En *formbinder* er principielt som en klampe, man anvender i støbeformen til betonvægge. Formbinderen har en udvidet arkitektonisk betydning for den fleksible forskalling støbt på stedet. Placering af formbindere styrer tekstilets udposninger. Endeskivens geometri overføres som *impacto*, dvs. tryk, til betonoverfladen. Hvor middelalderens kirkebyggere indmurede såkaldte lydpotter, kan formbinderen inddrage moderne akustiske materialer og teknikker og herigennem regulere akustikken. Individuelle formbindere kan definere en frit formet forskallingsflade, mens formbindere i form af et net får en *tekstil karakter* og åbner for flere betydningslag: Er tekstilet nu blot en stofbeholder, hvis form og betydning hentes udefra, eller er det tekstilets egen fysiske vævning, der giver betydning? Præcise trækfolder i tekstil kan fastfryses med tynde lag fiberbeton og skabe strukturelle, nærmest muskellignende dobbeltkrumme skaller (jf. professor Mark Wests pionerarbejder de seneste ti år på forskningscenteret CAST på University of Manitoba i Canada).

Med et udstillingsobjekt har jeg forsøgt at udfordre betons image og den udtalte tvetydighed i ordet tekstilforskalling. *Ambiguous Chair* er et objekt udformet som en 'polstret' betonstol. Tekstilets mønster overførtes uhyre nøjagtigt til betonoverfladen, og sammen med et polstret, blødt look forvirres beskueren: Hvad er tekstil, hvad er beton?

Tekstilforskallingens anvendelsesmuligheder skal forstås ud fra beton som materiale og proces, hvor både det sansede materiale og forskallingens resultat indeholdes i den arkitektoniske betydning. Samtidig kan udviklingen af betons arkitektoniske ordforråd være med til at øge forståelsen af og udnyttelsen af betons til stadighed udvidede egenskaber, om den er støbt i tekstil eller ej.

concretely.blogspot.com

Anne-Mette Manelius er arkitekt og erhvervs-ph.d. stipendiat ved Kunstakademiets Arkitektskole, SHL architects og E. Pihl & Søn.

TWO ABSTRACTS
The Second International Conference on Flexible Formwork

FORMWORK TECTONICS – RHETORICAL AND INSTRUMENTAL ROLES IN FABRIC FORMWORK FOR CONCRETE

Anne-Mette Manelius

Accepted abstract for technical paper for
the Second International Conference on Flexible Formwork, Bath, United Kingdom, June 27-29 2012

This paper is based on the author's doctoral thesis Fabric Formwork for Concrete - Architectural Potentials. Departing from a twofold view on rhetorical and instrumental roles of technology, it is suggested in the paper that architectural potentials of fabric forming may be further articulated through focusing on these roles in formwork tectonics of the textile, the form tie, and the frame.

Of the three tectonic formwork elements, only the specific roles of textiles are presented in the paper as results of analytical studies of the formwork principles and construction of three prototypes cast in fabric formwork:
A) Fabric-Formed Rigid Mold, by CAST, involves three types of textile with different rhetorical and instrumental roles that transform during the making of the prototype leading to new significance of the application of reinforcement textiles in concrete
B) Composite Column, by the author, involves a 'composite wood textile'; a backing-textile is structurally 'embracing' and properties of wooden formwork boards signify form and concrete surface
C) Ambiguous Chair, by the author, in which furniture textile are used as formwork for a chair. The instrumental role of the formwork textile transforms to become strongly rhetorical; expressed stronger than the actual concrete in the concrete form, surface and 'affordance'.

EXPERIMENTAL DATA – FABRIC-FORMED CONCRETE AS MATERIAL AND PROCESS

Anne-Mette Manelius

Accepted abstract for technical paper for
the Second International Conference on Flexible Formwork, Bath, United Kingdom, June 27-29 2012

The PhD-thesis, Fabric Formwork for Concrete - Architectural Potentials on which this paper is based, is influenced by research- and teaching methodologies at the University of Edinburgh.

The paper contains three parts: an introduction to the term stereogeneity; the methodology for the production of 'experimental data' in experiments and student workshops that include the conception and construction of fabric formed concrete structures; and finally an approach to analyzing this data.

The tectonic can be described as the expressed physical manifestation of structural principles into materials and methods of construction. Tectonic discourse lacks a specification of the tectonic specific to concrete construction; the Greek term stereogenés (stereogeneity in English) is introduced in the paper; it consists of the adjectives stereos, solid and genés, procedure of becoming.

'Experimental data' has been produced during experiments done by the author and workshops done with students, and consist of three categories: Sketches and written reflections of structural formwork principles; documentations of the construction process in writing and photographs; and the physical, stereogeneous consequence. The data describes processes of rhetorical and instrumental construction of fabric formwork and concrete as material and process. With the aim to formulate architectural potentials for fabric formwork, Stereogeneity is used to describe and analyze the relations between the data categories.

ARTICLE

THE ROLE OF MATERIAL EVIDENCE IN FABRIC FORMWORK FOR CONCRETE

Anne-Mette Manelius

Article published in
Beim, Anne, and Mette Ramsgaard Thomsen, eds.
The Role of Material Evidence in Architectural Research.
Copenhagen, Denmark: RDAFASA, 2012. 94-97

Fabric formwork is a new formwork technology in which sheets of woven textiles are used as flexible, lightweight formwork for concrete structures.

This Industrial PhD project has its focus on exploring the architectural potentials of fabric formwork for concrete structures. Potentials are investigated in a theoretical framework of tectonic discourse, and with regard to form, surface and production of concrete.

The term *fabric formwork* seemingly contains an embedded contradiction, an oxymoron. Cultural associations to textiles and concrete lie in the lightness and narrative of textiles, and in the heaviness and rigidity of concrete. This cultural conception of material properties leaves room for elaboration, yet it frames a theoretical problem of concrete construction at deeper level.

Tectonic discourse was influenced mainly by the writings of Gottfried Semper[1] before concrete had been rediscovered. The two basic notions of the tectonics of the frame and the stereotomics of stone do not cover the multiple procedures of pouring concrete into a constructed mould as a manifestation of initial structural principles; there is a lack in the tectonic terminology with regard to concrete construction.

Other challenges for fabric formwork lie at a technological level. Textile principles and traditional practice regarding concrete construction are far from similar. It is not straightforward to transfer textile technologies to the concrete industry, and at the same time textiles used as formwork will affect how we think of concrete construction and architecture.

The relevance of the study lies in two areas that can be summarised as: concrete evolution and textile revolution.

Concrete is the most commonly used building material worldwide, and contemporary Danish building is based on reinforced concrete, mostly produced in the form of prefabricated elements. Developments in digital design and engineering tools have changed the way architecture is conceived and calculated. However, concrete structures are produced using methods that have not changed for half a century, despite new developments in technologies for concrete and formwork materials.

The architectural vocabulary of concrete can be developed with regard to form, structure and surface in order to exploit the liquid origins of concrete when wet. There are potentials with regard to both prefab and on-site concrete production.

Textile technologies have undergone an immense, almost revolutionary technical development in which existing production techniques are combined with new or alternative material fibres and scales in order to produce flexible, strong and light sheets of fabric with new material properties and at affordable prices. It is the assertion in this thesis that the considerate use of textile technologies in formwork for concrete may articulate potentials of concrete in architecture through enhanced expression of materiality and processes of 'becoming'. Through the affiliation with a large contractor and an architectural office, the project frames the topic in a Danish context of concrete building and further elaborates on research by pioneers in research and building.[2]

The aim of the project is to formulate strategies for the future implementation of fabric formwork for concrete in architecture. Potentials will be discussed at two levels: potentials with regard to the formwork technology itself, and potentials regarding concrete structures formed by fabric.

In other words, how can concrete be used in new locations at a low-tech level, and what are the formal and structural potentials of concrete which can be unfolded at a more technologically evolved/developed level.

METHODOLOGY – RESEARCH THROUGH DESIGN

The project involves research *through* design.[3] The empirical data of the project is produced through two types of experimental practice: Student workshops and the author's own experiments. Workshops include designing and constructing principles for formwork structures; pouring concrete into these structures; and finally stripping the concrete pieces to reveal the concrete structure. The remains of these processes are *material evidence* or *experimental data*, tons of hardened concrete with a strong material presence which express the direct formal consequence of the formwork tectonics as well as expressing the embedded oxymoron in the technology. Besides, or actually before the concrete evidence, the experimental practice creates further valuable material to be evaluated, namely the fabric formwork structures designed and constructed for the concrete pieces. The design and construction process is documented through drawing, photos and written reflection.

The formwork vocabulary formulated through analysis studies of the *experimental data* is further elaborated and discussed for its potential 'evolutionary' impact on conventional concrete construction, and on the articulation of formwork tectonics.

To sum up, there are three types of experimental data in this thesis: sketches of design concepts; documentation of construction processes; and the remaining concrete structures.

THE ROLE OF MATERIAL EVIDENCE WHEN EXPLORING FABRIC FORMWORK

The workshop activities that generate the concrete data of the project could be seen in a similar light as Nervi,[5] who states that architecture is seen as a synthesis of technology and art. The assertion then is that artistic explorations of technology and technological testing through artistic practice (material workshops) may work as fruitful, parallel and overlapping research approaches.

The individually designed concrete objects have a highly expressive presence. Along with these obvious decorative and formal aspects for concrete as *material*, the experimental data includes data to describe concrete as *process*.

The complex and multi-facetted set of data is analysed in order to further elaborate the tectonic terminology involved in rhetorical and instrumental construction of concrete. With a deeply rooted architectural vocabulary at hand, the tectonic understanding of fabric formwork and fabric-formed concrete may point towards the possible application in contemporary construction.

Bibliography and References

1 Semper, Gottfried. *The Four Elements of Architecture and Other Writings*. Cambridge ;;New York: Cambridge University Press, 2010.

2 CAST. "CAST :: CV Mark West." About Mark West, director at CAST, 2010. http://www.umanitoba.ca/cast_building/people/mark_west.html.; Chandler, Alan, and Remo Pedreschi, eds. *Fabric Formwork*. RIBA Publishing, 2007.

3 Frayling, Christopher. "Research in Art and Design" 1, no. 1. Royal College of Art Research Papers (1994 1993): 1-5; Sheil, Bob, ed. *Design Through Making*. Chichester: Wiley-Academy, 2005.

4 Nervi, Pier Luigi. *Aesthetics and Technology in Building – the Charles Eliot Norton Lectures*, 1961-1962. Harvard University Press, 1965.

E-MAIL

THE ROLE OF PHYSICAL MODELS

The following is an excerpt of the response to questions posed in an email by the Dutch PhD student Diederik Veenendaal, ETH Zürich, February 1 2012.
The refelections in the response relate to the role of physical models in research.

Questions in italic as posed by Veenendaal.

1) Which of the following physical modelling techniques have you used?
- plaster models
- water tests (small/full-scale)
- concrete models (small/full-scale)
- other techniques?

I have made plaster models myself. During student workshops I have also encouraged to test their formwork principles in plaster models as well.

Also sand has been used in small-scale models a few times but not documented very well.

For one workshop students were given 'test'formwork (from a technical concrete lab) which they lined as well as filled with material samples and compositions to only test surface structres

One workshop was long enough for students to first make plaster models, then a 1:1 detail study in concrete, and finally full-scale concrete models.

Most workshops only included one small plaster model (1:5) and full-scale concrete models (100-210 cm high)

2) If you've made small-scale models, how have these informed later full-scale models, mock-ups, prototypes, projects?

The relation is quite direct!
And several aspects are involved. For many students, the hydrostatic pressure in general, as well as the difference between the pressure in the bottom and at the top was surprisingly large.
Adjustments in detailing could thus be made.

In general the principle remained the same in the small and the large models. Also, failures were similar. Students tended to underestimate their findings and scale them up accordingly.

Students have expressed how they learned a lot from making the little models.
This is one aspect – the other is about pedagogy… in order to make one little model, there are still many decisions to be made –
If groups could not agree on ideas – it is simple to ask them to test both ideas in a model – and let them base their judgment on their findings – this has had tremendous effects – on productivity as well as the growing level of knowledge and self-esteem as students made qualified decisions based on the own empiric data.

3) If you've used full-scale models, to be replicated later, what were the reasons for doing a full-scale model, rather than only small-scale models or doing the construction straight away?

I have not.

4) Have you in any way been restricted in terms of time, space or budget in doing a certain type of physical modelling?

We do not have any 'wet workshop' facilities at the school (to do casting). I have been invited to use the technical university – here there are poor wood workshop facilities.
This has affected the framework for my studies – most have been grouped around the student workshops where a group would be located in workshops – and we would get concrete from a truck.
The lack of workshop space has caused valuable time to be wasted when students and formwork structures had to be transported from another facility 15 km away--- workshop facilities are crucial for these studies.

5) Do other advantages or drawbacks come to mind for these techniques relative to one another (not related to scale, time, budget or space)?

In general, my students have had 5 working days prior to casting full-scale concrete– so time permitted only one series of small cast models. For the one workshop where there was more time – the combination of plaster and concrete models really informed the final prototypes – they could achieve a higher level of complexity in their investigations.

My research practice includes teaching students as well as collaboration with a larger contractor – the full-scale models have been important for both corners of the aspect. Students were learning by doing.
And contractors talk in process – and in scale – my experience is, that they can relate well to full-scale testing!!

6) Have you or your students experimented with digital modelling for fabric formworks? How were these experiences?
The project for my own part has been completely analogue.

A few students have independently experimented with digital modeling to form the basis for either formwork or the design object as part of a workshop assignment.
An example: workshop TEK1, 2011 – the assignment was a bench.

Most have confused the media - They designed a curvy bench using only spline and extrusion tools because they were inexperienced with any digi-tools at their first semester. This has greatly limited their view on the opportunities with fabric formwork and they struggled to make the formwork 'fit' the design.

One group had a member familiar with Grasshopper – and had found images online of fabric formwork principles. This had a great effect – because they translated their understanding of the construction principle to the digi-tool. – they interpreted what they saw - but the students did not invent a new method –

The limiting factor to both is somehow the apparent restriction of their creativity – students were inspired by other versions – or limited by their technical abilities in using tools that represent the very method they were learning. Instead of openly questioning which materials and techniques they had at hand.

Another drawback is the lack of the imagination of the processes of construction. the digi-model looks so finished –

One assignment included a storyboard in order to encourage students to consider the processes and details of construction.

I am making a total generalization – but it is my impression that students who did not use digi-tools were more in sync with actually constructing- they were better at communicating the significance of the knowledge of buildability – instead of showing a rendering in their report...

My project focuses in specific on the formwork tectonics of fabric formwork. This focus has elaborated from the realization that students are learning the basics of construction through making. And the direct relation between construction principles, techniques and materials of the formwork, on one side – and the 'formal consequence' on concrete form and surface, on the other.