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Lightn' Porcelain: Envisioning scales of light and material in the realm of 3D-printing

Introduction

The way light reveals form, construction and material has occupied architects, designers, artists, and craftsmen for centuries. Light provides visual information of form and material and thus bring a certain perception to how objects, spaces and buildings are observed and experienced. (Arnheim, 1969; Lam, 1977; Böhme, 2013; Cuttle, 2015). 3D-printing has brought new ways to create form and thereby also new potential to the emergence of material by means of light. In this paper, we explore and discuss how illuminated 3D-printed porcelain can create new expressions and atmosphere to be envisioned by shifts in work operations, scale and representation. The project is a collaboration between an architect specializing in lighting and a ceramic designer specializing in 3D printing with the aim of studying how light and 3D-printed material can inform one another across the fields of design and architecture.

The form generating logics and practicalities of 3D-printing have brought new ways to give form and are adopted by many design professions by the way a 3D-printer transforms digital information into a physical object and build up added layers of printable material (Hoskins, 2013). A potential of 3D-printing within the fields of design and architecture is how easy it is to obtain a visual effect, when combining light with geometries and materials of 3D-prints. Being based on a parametric design, 3D-printing offer complex forms and variations, which immediately catches the eye by the way light traverses the material and openings in the print and how gradients of light and shadow occur. By first sight this is a potential, but we also experience a challenge because of the complexity of parametric design in relation to the material qualities and form printed. Therefore, we suggest studies of light in relation to 3D-printed material to learn more about how 3D-printed material expression is created and 'tuned' by means of light with the purpose to create material atmosphere and experience.

The experimental pavilion „Bloom" by Emerging Objects[1] exemplifies the potentials of 3D-printing in relation to light; the pavilion is made by 3D-printed blocks out of cement into a lightweight self-bearing structure, which creates a play of light and shadow on the inside, made by how the form and the structure of the pavilion allow daylight from outside to pass to the inside (Rael and San Fratello, 2018). Another example is the project "Harnessing plastic deformation in porous 3D

[1] Images, work process and partnership of „Bloom" are described in the book „Printing Architecture. Innovative Recipes for 3D Printing" and at http://emergingobjects.com/project/bloom-2/

printed ceramic light screens" by Clarke-Hicks et al (2022), where functionally graded 3D-printed ceramic screens are produced for decorative lighting applications. In the project Clarke-Hicks et al explore methods involved in altering plastic deformation during the wet-processing of porous clay structures and the corresponding light-scattering behaviour of their ceramic counterparts.

The above-mentioned projects are representative examples of how 3D-printing enable to obtain certain visual appearances when combined with light. But while these projects work in a scale of full size, we are in this project rather occupied by the potential of how light and a small size 3D-printed object enable us to envision illuminated material in more architectural scales. Thus, this paper concerns the theme of scale and representation, and how an architectural model can be produced, explored, and represented as an object of scalability by means of 3D-printing.

A study of light and 3D-printed material to enhance one another

With an interest in how light and 3D-printed material create atmosphere by enhancing each other's presence, the 3D-printed object is regarded a light-like object. By a light-like object we refer to the German philosopher Gernot Böhme and one of his notions of light related to the creation of atmosphere. Emphasizing that the perception of light does not require the simultaneous experience of a light source, Böhme makes a distinction to what he refers to as a 'light-like object' (Böhme and Engels-Schwarzpaul, 2017). To Böhme a 'light-like object' can be a luminous ceiling or the coloured glass window in a Gothic church, appearing as a luminous wall. In other words, light when experienced as a luminous object.

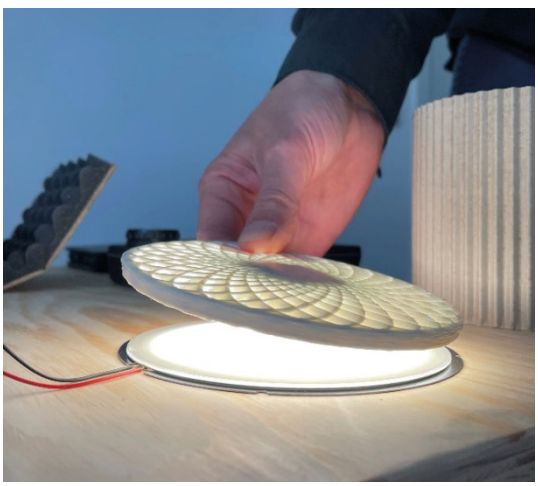

Fig. 01. The parts of the 'light-like object'
Source: Tvede-Hansen and Bülow

The 'light-like object' consists in our case of 3D-printed, fired, and glazed porcelain illuminated by an organic light emitting diode (OLED). This combination makes a design system in which the OLED works as constant luminosity and the 3D-prints as variations of geometric patterns to be tested, allowing the discovery of ways to create atmosphere for the use of architectural representation, see figure 01.

Of importance to us is Böhme's understanding of lighting as atmosphere to be experienced by the appearance of light in space and on things, and that it is a phenomenon to be understood and tuned by variations of colours, distribution, intensity, concentration, and diffusion of light. According to Böhme, light creates appearances such as brilliance, flickering, radiance, iridescence, fluorescence depending on the surface of a material (Böhme and Engels-Schwarzpaul, 2017). Just like the Danish Architect Steen Eiler Rasmussen recognizes the way daylight makes valuable objects behind the windows of old merchants' houses in Amsterdam appear sumptuous by enhancing the material qualities (Rasmussen, 1957, 1992), Böhme understands how light and material can blur or enhance each other's mutual presence by saying:

> We can indeed see things in the light, without actually noticing the light about them. However, in the case of brilliance and shimmer, light become explicit about things.[2]

Observing material expressions by means of light - and vice versa - the expressions of light by means of the material, we explore how atmosphere emerges when bringing light and 3D-printed porcelain into a light-like object. The atmosphere of the light-like object is further explored by envisioning architecture in various scales. Joining the even light from OLED and the geometry of the glazed, slightly translucent 3D-printed porcelain, we ask: What kind of atmosphere will a light-like object in this project be able to produce? How can the light from OLED and porcelain enhance each other's presence? How can a light-like object become scalable and able to represent architecture? And, what kind of architeture is envisioned using illuminated 3D-printed porcelain to represent architecture?

The iteration process

The study reflected an iterative process that was composed of five operations creating an output, see figure 02. Operation A was developing a digital representation based on a digital parametric setup, which made up the path for 3D-printing in porcelain (operation B). Operation C was firing the 3D printed porcelain, which was then combined with the OLED light source to produce a light-like object (operation D). Finally, the light-like object was explored as an architectural representation through photography envisioning illuminated architecture (operation E). Operations A, B and C was developed in a feed-back-loop that built up an understanding of the relationship between the digital representation and the fired ceramic object, while the operations E and D reflected individual in-depth studies. Furthermore, the study of the light-like object enabled a feed-back-loop to rethink the previous operations.

[2] Böhme, G., & Engels-Schwarzpaul, A.-C. (2017). *Atmospheric architectures: The aesthetics of felt spaces*. London: Bloomsbury Academic, Bloomsbury Publishing. p. 155.

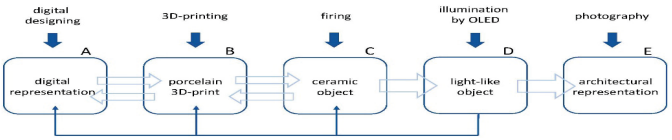

Fig. 02. Iteration Process
Source: Bülow and Tvede-Hansen

Digital preparation, physical printing and firing

The 3D modelling software Rhino and its graphical programming interface Grasshopper was used to create the parametric setup for the digital design of the porcelain to be 3D-printed (operation A). The parametric setup allowed dynamically for a range of patterns within the capabilities of the 3D printer, see figure 03. This setup enabled us to explore a pattern before it was printed e.g., in relation to dynamics between open and closed areas, curved and straight lines as shown in figure 03. The initial digital design was of great importance to the 3D-printing of the porcelain, since the amount of lines as well as the shape of the lines had to be adjusted in relation to the size of the coil produced by the 3D printer. In our setup the digital printhead simply produced a coil of porcelain along the line's shape and position referring to the digital designed line that made up the pattern (operation B), see figure 04.

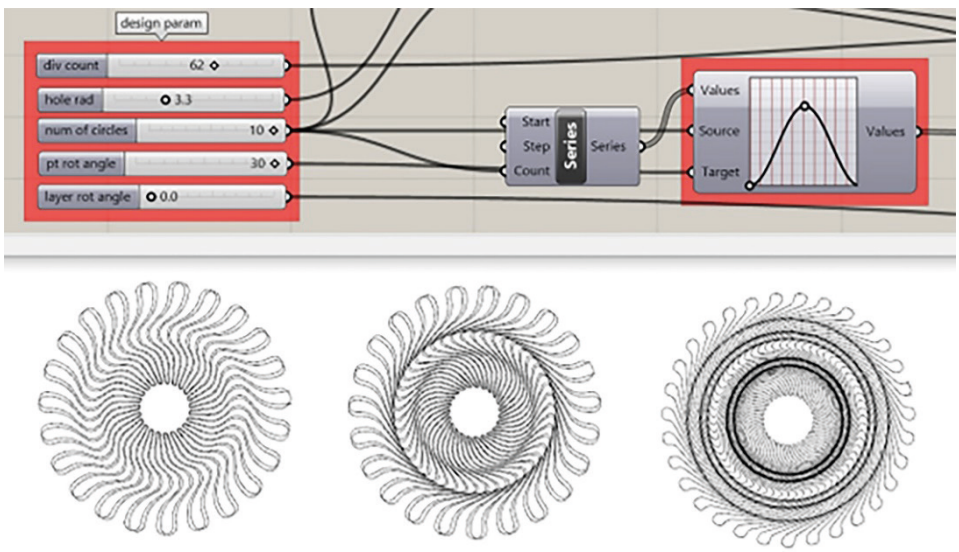

Fig. 03. The parametric setup for digital design
Source: Lim, Tvede-Hansen

Porcelain is known for its fine particles and translucency when fired. The degree of translucency is related to the thickness of the wall. The thinner the wall is, the more translucency. To experiment with the 3D-printed porcelain in relation to the digital design we challenged the material in relation to gravity by printing on lasercutted forms in foam, to be placed below the 3D-print, see figure 04. The foam acted as add-ons to the digitally controlled print. The add-on changed the usual flat foundation into

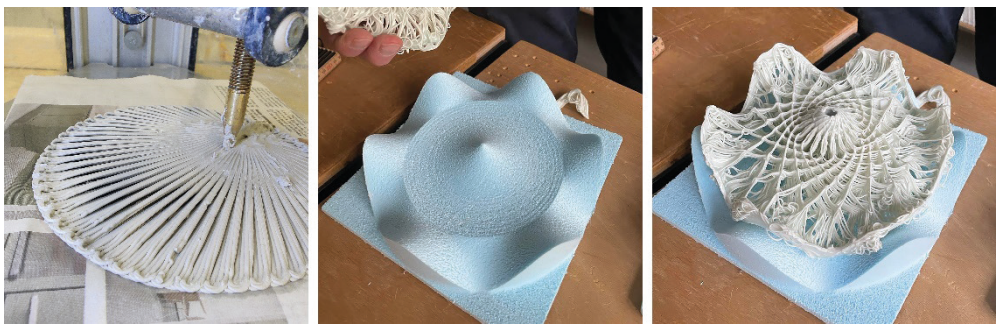

Fig. 04. 3D-printing in porcelain, lasercutted foam and 3D print on foam
Source: Tvede-Hansen

higher and lower areas in relation to the 3D-print, which enabled us to explore and challenge the extruded porcelain as tiny and refined layered coils that naturally hang in relation to gravity. The results partly dissolved the pattern into to the behaviour of free hanging coils of porcelain and revealed new unforeseen expressions and openings in the pattern, see figure 04. Furthermore, this new expression was explored in relation to the firing process, which through a chemical process transforms the porcelain and develops the translucency in relation to the glaze (operation C).

The light-like object

The circular 3D-printed porcelain was added to a circular OLED of 12 cm in diameter in order to establish a light-like object in the understanding of Böhme. Light from the OLED positioned below the 3D print would traverse through material and openings in the printed geometry and reflect from the surfaces of the porcelain. Preparing the light-like object to represent architecture, two sub-operations took place; 1) investigating the appearance of the light-like object by means of the light from OLED and the 3D-print, 2) make the light-like object into a spatial structure.

Comparing series of backlit 3D-printed porcelain of different geometrical patterns, glazed with glaze of variating thickness, and printed with or without add-ons of lasercut foam, different appearances and atmospheres was distinguished according to how the light from the OLED would traverse the 3D-prints, see figure 05.

Appearance of the light-like object

In some 3D-prints, the light from the OLED would create large variation of direct and filtered light, resulting in contrasting appearance of brightness and shadow. In 3D-prints not allowing direct light from the OLED to pass, the translucent qualities of the porcelain would appear together with light reflected from the covering surfaces

creating a clear pattern made by the parametric form and the layer of porcelain, receiving more or less light.

A range of visual merge between the OLED, the light and the 3D-printed porcelain emerged. In one end of the range the 3D-prints would appear as two different objects, in the other end they would appear as one light-like object. The emergence of the one light-like object was established partly by the openings through and across the coils of porcelain, made by the printing technique developed, and by light reflecting the whiteness of the porcelain as well as traversing the thick layer of glaze, only covering parts of the print. Together, the light, the porcelain and the thick glaze created a wide number of gradients between bright and dark areas as well as a subtle gradients between cool and warm shades of colour.

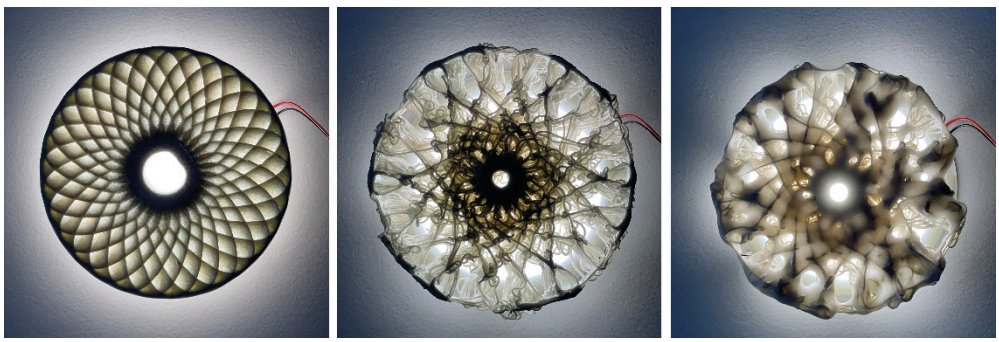

Fig. 05. Light-like object studies
Source: Tvede-Hansen and Bülow'

Development of the joined light-like object was depended on the iteration process and a growing understanding of the correspondence between the digital representation of the print to be printed, the geometrical pattern of the 3D-printed porcelain, the firing and glazing of the ceramic object and how the ceramic object would appear together with the light from the OLED. It became just as much a matter of the physical 3D-printed porcelain forming the parametric setup as of the parametric setup forming the 3D-printed porcelain.

The light-like object as a spatial structure

The sub-operation, to join the porcelain and the OLED light source in a spatial structure, was established to bring spatial qualities to the light-like object in order to further investigate it as an architectural representation. Making it spatial required additional elements. Bendable sticks out of brass was used to fix the 3D-printed porcelain and the OLED in position through holes in a ring attached to the OLED. This simple solution allowed for more spatial structures of a light-like object to be

created and studied. The spatial structures allowed observation from many angles, bringing understanding to the distinctness of each individual item of a structure and how it was joined, see figure 06.

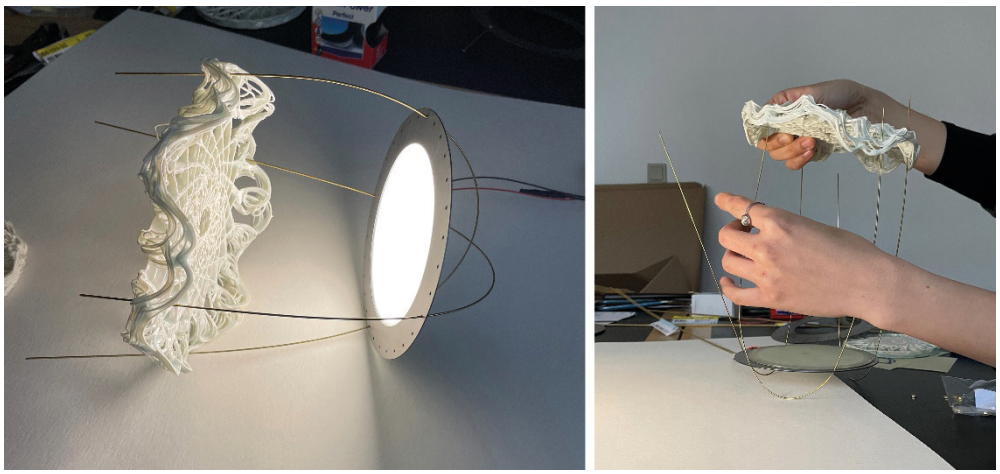

Fig. 06. Light-like object made into a spatial structure
Source: Tvede-Hansen, Bülow, Lim

The architectural representation

The light-like objects were created partly by the iteration proces and partly by means of the internal compositional balance between light, material, pattern, and additional parts. In order to represent architecture, they could thus be of any scale. Using the classic method of adding a scale figure to the illuminated 3D-print, the scalable potential became evident; the illuminated 3D-print would appear in various sizes according to the size of the scale figure added. While the size of a scale figure became an agent to envision the scale of an illuminated 3D-print, the number of scale figures and how they suggested occupancy allowed the illuminated 3D-print to envision a certain architectural element. If a few figures in 1:50 would relate to a horizontally positioned 3D-print, it would envision a light-like urban element, if many figures in 1:200 would pass a vertical positioned 3D-print, it would envision a light-like façade, see figure 07 and 08.

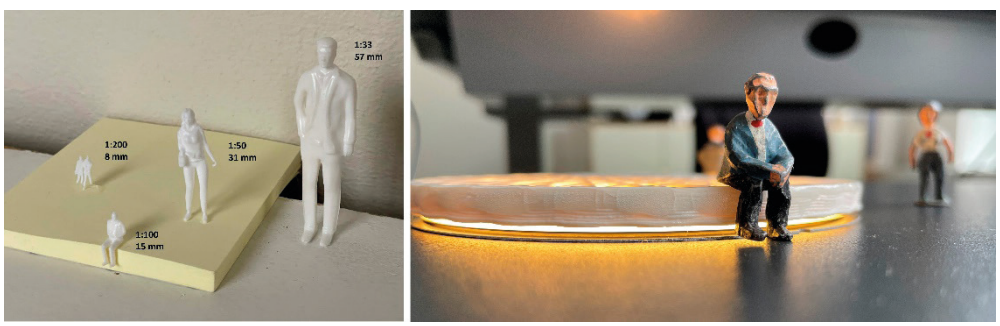

Fig. 07. Size of scale figures
Source: Bülow

Exploration by photography

The illuminated 3D-prints was further explored through photography, which added more opportunites to envision the light-like object in scales of architecture. The way to frame the image and position a potential observer with regards to distance and eye level brought various ways to represent the illuminated materiality. Framing

Fig. 08. Scale figures and the light-like object
Source: Bülow, Tvede-Hansen

e.g., only a part of the light-like object and position the camera at a low eye level near the illuminated 3D-print, the atmosphere of the light-like object would magnify into that coming from a large structure, see figure 08. A group of small size scale figures, placed like if they pass a building, receives light on one side and emphasizes the way light emanates from e.g., a facade.

By photographic framing and close-up view attention to gradients of shades,

colours, shine as well as the layer of coils is directed. Warm white, pale orange and turquoise colours, created from the firing, emerge and the lustre of the glaze and the lustreless of the non-glazed parts become central to the representation. Together with the gradients of light and shadow, the irregular geometric pattern of thin extruded layers of porcelain, an inviting light-like façade appears, which seems to drop the material as if it was textile, at the same time as holding on to itself, see figure 08.

The scale figures played an important role exploring the light-like object through photography. Not only to envision an imagined size of the light-like object, but also to invistigate atmosphere as it could appear by different kinds of use and in various scales. This observation is supported by American architect and researcher, Alex T. Anderson, who states that people understand the world through the body's ability to act in things (Anderson, 2002). Anderson believes an important role to scale figures is to demonstrate not only scale, but also to envision a possible future. Being lit from the side by the illuminated 3D-print, the scale figures enhance the envisioning of a lively and inviting facade created by the atmosphere of the light-like object. It looks like the figures pass the facade while on their way somewhere else not within the frame of the image.

Shifting media and scale

To the architectural theorist Philippe Boudon, a matter to the architect regarding scale is the concept of *shifting.* What is not yet built is investigated in other media before construction (Boudon, 1999). In addition, Boudon states "Architectural design is not a gradual step-by-step transfer from one scale to another, developing towards a ratio of 1:1" (Yabena, 2005). Architectural anthropologist Albena Yavena (2005) also builds on this concept in her article "Scaling Up and Down: Extraction Trials in Architectural Design" in which she unfolds ethnographic research on architects designing a large and complex building. During the project work the architects produce loads of physical models of various scales while designing, observing, and discussing. After multiple up and down transitions between small- and large-scale models, the building emerges, becomes visible, material real, which reflects the architects' cognitive implications and how they involve themselves in a comprehensive dialogue with materials (Yavena, 2005).

Improvements of ways to produce, explore and represent architectural models since these writings of Boudon and Yavena include 3D-printing. By requiring a digital file to make the physical print, 3D-printing connects the digital realm with a physical output. Hereby a profound *shift* between digital representation of no scale and the size of the physical print takes place. Within the field of architecture, the 3D-print itself can take more directions regarding scale, e.g., the 3D-print can be in a scale of full size, when printing modular elements for architecture or even buildings.

The 3D-print as a physical model

Nevertheless, the 3D-print can also be scaled with the purpose to become a physical architectural model. To provide an example of an architectural model, we can use our light-like object to demonstrate a design process of more *shifts.* First, the object was printed in porcelain in a size that reflected the digital geometry. Second, the object was fired, where it went through a chemical transformation before it was

created and explored as a light-like object. The exploration of the light-like object made a *shift* while we investigated the appearances based on light in relation to the form and materiality of the 3D-printed porcelain. Furthermore, the exploration of the light-like object enabled a feed-back-loop to rethink the previous operations of digital designing, 3D-printing and firing to understand the becoming of the light-like object's appearances and to refine it. Finally, the *shift* towards scalability took place, when the light-like object was further created and explored as an illuminated material representation of various architectural scales.

The many *shifts* of this iteration process might seem laborious, but they brought a growing and thorough knowledge of how relations between a 3D-printed material and a light source create appearance and atmosphere. If the methodology used in this iteration process was to be part of the development of an architectural project, the study of illuminated 3D-printed material could work as the initial, inspirational, and open-minded exploration or as a study running on the side with the aim of discovering new appearances and atmospheres created by specific combinations of light, form, and 3D-printed material.

A potential of studying illuminated 3D-printed porcelain for envisioning architecture is the fact, that clay has great potential when 3D-printing in scales of architecture (Rael and San Fratello, 2018). Some of the appearances created could be obtained by printing modular elements, another option could be to create new material appearance by means of light inspired by the photographic explorations of architectural representation.

Conclusion

In this study we explored 3D-printing within the field of ceramic design to discover how 3D-printed porcelain and light can inspire and influence the envisioning of architecture. The study allowed for an explorative approach, offering alternative ways to use the actual size of 3D-printed porcelain. Creating the light-like object to become an architectural representation of architecture was based on continuously shifts between the digital representation, 3D-printing in porcelain and firing that was investigated in relation to the OLED light source. The iterative process towards the architectural representation consisted of feed-back-loops and ongoing adjustments, which refined the result.

The 3D-printed porcelain was created as an object defined by its own mutual measurements, form, and materiality. When adding light for studying the various appearances the 3D-print became a light-like object according to Böhme's notion of atmosphere in relation to the experience of light. The light from OLED and the 3D-printed porcelain enhanced each other's presence by a more irregular pattern and uneven cover of glaze, made possible by the grain size of the porcelain and the lasercutted foam used during the printing, allowing light to transfer the 3D-print in a varied way. This technique resulted in a warm and inviting atmosphere and a multi-facetted and sophisticated appearance, expressing the physical result of the 3D-print process.

Scalability was established by adding scale figures of different sizes to the illuminated 3D-print. The size of the scale figures and the way they seemed to relate

to the light-like object created the possibilities to envision the illuminated 3D-print in sizes of architecture. Exploring and representing the illuminated 3D-print by photography expanded the possibilities of envisioning architecture by the atmosphere created. The atmosphere was created by the even light distribution of OLED and the material qualities of the 3D-printed and fired porcelain. The atmosphere discovered could be re-established by large scale 3D-printing in other material or taken further in another explorative proces.

As discussed by Boudon and Yabena, we consider the concept of shifting and the investigation of the architectural representation in other media and scales while designing, observing, and discussing of great importance to discover new ways of envisioning and representing architecture. Especially in relation to the emergent and fast development of digital and lighting technologies we see a great potential turning to the traditional fields within crafting, such as ceramics, to discover new atmospheres for architecture, because of the diversities in media and materiality.

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