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Introduction

This paper explores a process to archive spatial memory; from recording by 3D scanning, decluttering, sorting and finally representing and communicating information. It builds upon a background and theoretical framing, vital foundation to place it contextually and socially. In the dual character of the paper, foundation and case study of the proposed system are equally important, contributing on different levels of the same topic.

The background is based on how technical apparatuses are a non-distinctive part of contemporary human life. They define the means and limitations of recording and representing information, and by extension affect how memory is sustained through time. They are instruments which make information readable and graspable and in some cases represented as an image. These images, or by using Flusser's more descriptive term, technical images (Flusser 2011, 23), are affecting our memory of past events and define how culture is sustained through time, as if our memory of space is also affected by the means of which we record it.

Similarly to Stiegler's theory on the evolution of prosthesis, smartphones are the extension of hands (Stiegler 1998, 50); an a-live medium of recording, and source of retrieving information, forming a technical life increasingly available. Not that long ago in 2020, another generation of smartphones was introduced by Apple with an integrated LiDAR scanner (Apple, 2020). This 3D scanner can be therefore available to capture real time spatial data and it is considered as part of the archival medium genealogy. These mediums have an incorporated selection of the physical characteristics that are recorded and they define different perspectives of historical data. Specifically, 3D scanning, in the form of Point Clouds (PCLs), consists of two basic types of information: position and color, which after performing some basic operations are expressed as computational geometry and texture respectively (Fernandez-Diaz et al., 2007). These features are directly linked to time as they are affected by lightning conditions, reflections and all other parameters which affect the visual appearance of space (Figure 01).

Fig. 01. Visualizations from two 3D scans of the same space with different lightning conditions.
Source: Image from author.

In contrast to historical ortho-recording, where the past was connected with a delayed present and future, real-time recording, storing and transmitting is possible through “post-orthographic electronic surfaces" or interfaces, where our actions are enmeshed in “so-called real time” (May, pp. 33-34). Highly complex networks are communicated into a system of signals, where gestures (tapping, sliding, even looking) are translated into technical actions with momentarily response through interfaces.

Can we use this real-time depiction of post-orthographic surfaces as a dynamic tool for recording and organizing spatial memory through media traditionally used to represent space? In this exploration, by archiving temporal geometry on the cloud, all scale and time associations are dissolved, transforming it to an electro-topological entity. Physical space and time are signals, indicating the origin of recording. By creating the means of communication with this archive, one finds the oxymoron of re-setting time and scale in this case as signals; controls to allow retrieval and decluttering of information. Extended Reality (XR) is used as a medium to represent spatio-temporal information and by definition this information is related to its physical origin and it’s attached to physical space. Human experience is enhanced by the ability to explore and inhabit past spatial configurations of objects through an interface.

Part of the wider research is the creation of an interactive network of spatial information. In this context, spaces may create new electro-topological associations in a wider network, highlighting the importance of tool-based fusion, level of accessibility and experience. It's important to note that the technical aspects of the proposed research are beyond the scope of this paper, but it aims to provoke rethinking of assumptions based on space and time, outlining qualities of organizing and visualizing 3D data.

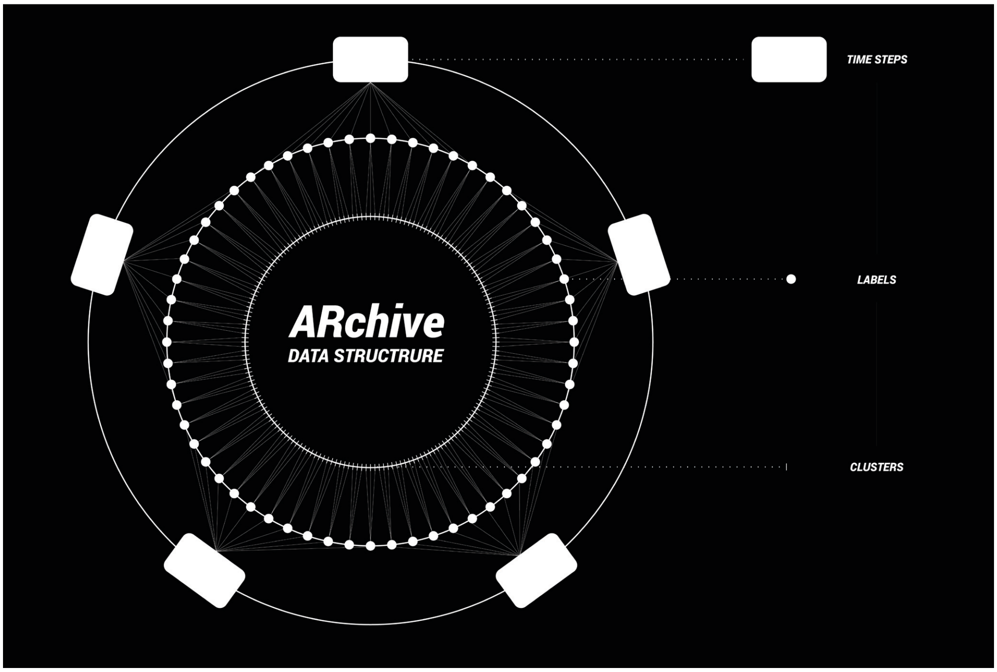

Fig. 02. 3D Data Structure: The information of the archival point clouds, XYZ and RGB, is organized based on time step, label (object definition) and cluster (individual objects).
Source: Image from author.

Background and theoretical framing

All knowledge, including technical knowledge, is filtered through the experiences and perspectives of the individual acquiring it and as Derrida explains, "ideal Objectivity is not fully constituted" or in other words, in order for information to be sustained through time it must be able to be incarnated in a transmissible form and be organized in a way to be readable and graspable (Derrida, 1989, p. 89). Additionally, constitutional systems, cultural erasure and power dynamics are shaping what information is preserved and how it is remembered, as dominant cultural narratives marginalize or erase alternative perspectives.

The compilation of a certain amount of information in one platform forms an archive, which is inherently directed to the medium of recording. Moving beyond a traditional definition of the terms, archive and medium are both different ways to describe the same system (Terrone, 34). What appears to be merely a passive repository of historical records, may in fact be a dynamic, and always incomplete entity which includes the act of recording and the means of communicating with the stored information. In parallel, the medium is used to materialize memory; historically humans have used different mediums to preserve and retrieve information. From the stone age, these mediums include a range from primitive drawings, language/ text, image and moving image, and the most relevant to this paper, 3D scanning and volumetric capture. The first two orthographic techniques embed a delay in the process of connecting thought and memory to materiality. Although every medium includes a delay in recording, it is highly relative to phenomenological time and human speed of perception (Ernst, 11). From twitter messages, to instant public sharing of photos, media culture seems to be obsessed with accelerating the perception of the present, or instead composing it anew.

The real-time transmission of information can take several representation forms such as sound and moving images. An example, experimenting by connecting cinema with LiDAR technology, is Volumetric Cinema by Current (Current, 2019). Narrative based visual content includes the third dimension, while space is constructed through the views of the user, in real time. 3D scanning has been also used extensively to more static ways of recording historical artifacts. Museums have attempted to replicate artifacts with 3D scanning. An example of that, is the British Museum, which has created a digital account to store and share 3D models on Sketchfab, an online 3D assets archive (The British Museum, 2014).

This increasing ability to digitalise our environment and behavior in real-time is generating vast amounts of data which can be decluttered, stored and create meaning, by caring cultural load. Artificial intelligence (AI), as a powerful human technological extension, is trained with this data, generating synthetic memory which in contrast to human memory, can be transferred and analyzed. Refik Anadol, a media artist, has extensively worked with data narratives, manipulating artificial memory as a tool to explore machinic alternate realities. His work is also highly related to the archival character of data, with an example of the project “Archive Dreaming” where a Machine Learning (ML) algorithm processed documents to create an immersive media installation through searching and sorting functionalities (Anadol, 2017). In the case of 3D scanning, PCLs represent spatial qualities through points in Euclidean space, with no formal structure or discretisation, but only the information of position and color. While humans conceive semantics by intuition, machines have been structured in a way to be trained and understand spatial semantics. Namely, scene understanding is the conceptualisation of a spatial representation as a way to get information on its contents and structure. It has matured through the years in 2D formats, such as image, but includes significant complexity when adding the third dimension (Singer and Asari, 2021, p. 97495). In parallel with the integration of LiDAR scanners in iPhones, Apple has also released RoomPlan, a library and API with scene understanding pre-made functionality, allowing non-specialist developers to create tools for parametric representation of physical space (Apple, 2022). This parametric representation allows access to semantic and dimensional information, such as types of furniture. Additionally, there are multiple Deep Learning (DL) models, trained on interior datasets with semantic labels, which are open source and accessible through GitHub (Nvidia, 2021). The multiplicity of technological advancements on both hardware and software, such as the above, are offering possibilities of redefining the notion of spatial archives. The methodology presented in this paper was initiated by this possibility, and involves an experimental approach with different techniques and mediums.

The above techniques of decluttering 3D data and specifically about predicting the semantics and segmenting them, are similar to indexing archives of other forms. Namely, the archivists need to describe their holdings in order to allow users to access them, while creating search tools with analogue or digital mediums (Bearman, 1989). Along with the hardware technology to capture data, the ways to access them has also evolved through time and it's mainly relying on the concept of indexing in order to then quickly access specified material. A well known technique is the control card system guideline of 2009 (Nurdin, 2021, p. 31), where each of the specified categories was assigned to a physical card. This analogue system was then expressed digitally on computers and the folder structure, where each folder has a name and its own structure. Later smartphones incorporated this logic with buttons representing actions to perform tasks or show information.

As elaborated above, space as well as every-day human actions and behaviors have become a system of signals, part of vast digital archives which machines can understand and use to generate further information. Temporality is a main attribute of archives and it has been expressed through different ways in fiction. In his book Time Travel: A History (Gleick, 2016), James Gleick explores how we think about time and why its directionality has been a matter of discourse for many years now, using philosophy through literature and physics. Science fiction has been an inspiration of technological advancements and has been extensively related to time-travel, while Gleick identifies its origin in the novel The Time Machine by Wells (Wells, 2002). Another more recent example is the movie Interstellar, where the space is represented based on time while the person is moving in an undefined space (Nolan, 2014). This area of research is linked to humans' perception of reality in terms of time and the nostalgia of what was here before us.

Methodology

The definition of archive is vast enough to accommodate different applications, from social media platforms and personal archives to state-governed infrastructures, it can be on a personal or group level, static or dynamic (Nurdin 2021, p. 29). Here the focus is on the flexibility of the archival system as a dynamic entity which can represent the outcome of past events that happened in a space and affected its geometry. Space in this paper is studied as a signalized version of the physical, as a set of points with RGB attributes. Additionally, time is an essential part of the archive; multiple momentary spatial states are recorded, decluttered and stored, organized based on time and semantics. Lastly, this spatio-temporal information is communicated through a mobile device, while superimposed and attached in the same space with XR technologies.

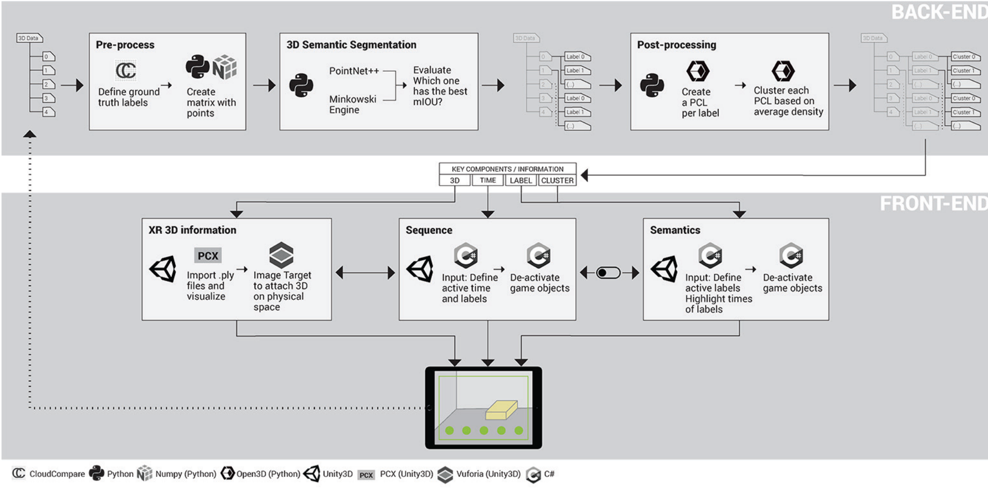

Fig. 06. Methodology diagram. The combination of methods is organized in the Back and Front-end. The dotted connection, to scan and upload new 3D models in the application, is not implemented in this paper, but it would be helpful for future work to close the loop.

Source: Image from author.

The selected case study is a bedroom, where the process started by collecting 3D scans of its architecture using appropriate technology (Figure 07). In this case, a smartphone (iPhone) interface with a LiDAR scanner (Apple, 2020) was used to capture depth information about the room's surfaces and objects. Regular intervals of scanning the bedroom created the first level of the archive; 3D information organized based on time, which includes the changes in spatial configuration of architecture and objects.

The outcome of 3D scanning is a technical image that falls within the spectrum of depictions and models, as Flusser defines the two district terms (Flusser 2011, 42). It is a depiction representing the actual space, while at the same time it can also be described as a model, in the current context, incorporating a possible configuration of the selected space on a specific time.

Fig. 07. Visualization of the case study's sequential input data. The resolution of the scans affected the quality and accuracy of the resulting 3D model. Higher resolution scans capture more detail and produce a more accurate representation of the room, while lower resolution scans may miss some small details or produce a less accurate model. The iPhone's LiDAR scanner has a resolution of approximately 1mm, which is sufficient for capturing most of the details in a typical bedroom. However,

the resolution of the scanner is limited by factors such as the distance to the object being scanned and the presence of any obstructions or reflections that may interfere with the sensor's ability to capture accurate depth data.

Source: Image from author.

Digitalisation of our environment and behavior, which means capturing and storing enormous amounts of data, is the way computers understand our reality. However, as argued in many publications, data is not that useful if we don't convert it into information (Pries and Dunnigan 2015, p. 153). Decluttering data to extract useful information can effectively be done using ML methodologies, which are able to recognize patterns and perform tasks much quicker than humans (Pries and Dunnigan 2015, p. 151). DL is a subset of ML that involves training artificial neural networks with multiple layers to recognize patterns in data. The key advantage of DL is its ability to automatically learn representations of data, rather than requiring explicit feature engineering by human experts. The semantics of space here are configured through semantic segmentation, making the type of object an additional index to the time parameter. More specifically, the Minkowski Engine (NVIDIA 2021) trained with the ScanNet dataset (Dai et al. 2017) was used to segment the PCL based on its individual objects (Figure 08).

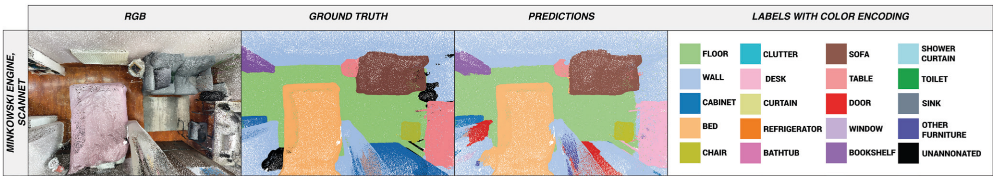

Fig. 08. Segmentation results from testing the Minkowski Engine trained with the ScanNet dataset. The first column showcases the 3D model, colored with RGB values, the second column is the manually annotated colors which correspond to a label and the third column is the predictions of the Minkowski Engine.

Source: Image from author.

Aiming to convert the above information into knowledge and make conclusions about the diversity, configuration and spatial change over time, a communication medium is made. Considering the possibility to enclose the whole process in a closed loop on the same device, from scanning and processing to storing and visualizing, the selected one here is an iPhone 12 Pro with an XR User Interface (UI). Unity3D (Unity Technologies, 2021) was chosen as the developing software with PCX (Takahashi, 2019) as a PCL renderer. Archive and medium in this case are both enmeshed into one experience of dynamic recording, incorporated into a device, the smartphone.

After 3D scanning, the PCLs are stored in the digital space, where scale is translated into information on a Euclidean coordinate system. Relating back this 3D information to physical space in the context of XR, requires an anchoring technique. Here an image target from Vuforia Engine (2021) was used to identify the orientation and position of the digital content on the physical environment. This image has a dual character and plays the role of the connector, minimizing the mental delay between object and digital artifact.

Any archival system requires indicators to filter and communicate the information stored. Visual cues and labels are parts of a system of signals, where real-time actions are represented on interfaces. These means of retrieval and interaction are expressed here as common UI tools in a 2D interface; sliders and buttons with text and color (Figure 09). At this stage the PCL archive consists of four kinds of information for each point in space: position, color, sequence and label. The first two are used for visualization of the segments. The next two are the main ways of organizing and communicating. The function of moving between different time levels in the 2D interface is represented through a rectangular slider, as seen in Figure 09. The design of the interface here is the process of sliding, both as a loop and linear, allowing to move from the present moment without any overlaid 3D information, to the past configurations augmented in the physical space and finally end up in the present again.

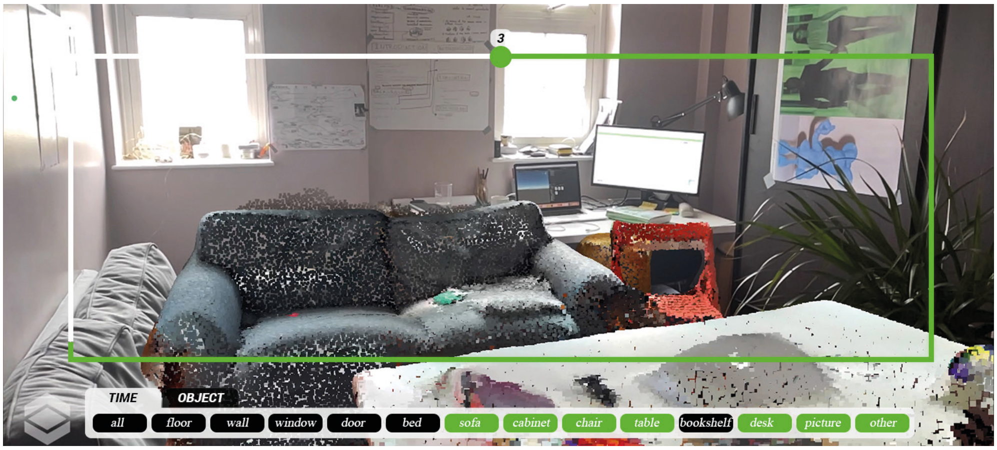

Fig. 09. The Time mode, where one can use the rectangular slider to de-activate different time levels, but also choose the shown objects with the specified labels through the buttons at the bottom of the screen.

Source: Image from author.

In parallel with the time slider and the organization based on time levels, the digital archive of 3D objects is also organized through the labels. The discrete objects comprising all the 3D scans, have their own local sub-archive: organized and cataloged information about their past states. In parallel with the logic of card separation (Nurdin 2021, p. 31), each label is represented through a button. Therefore one can select which of the labels or type of object will be visible in space. This function gives the possibility to track a specific object's past state or observe the overall change with all the labels activated. Additionally, the user is able to switch between the two different modes: TIME, to navigate through past states of the same space while having the ability to de/activate different labels, and OBJECT, to de/activate specific labels and track their origin in time (Figure 10).

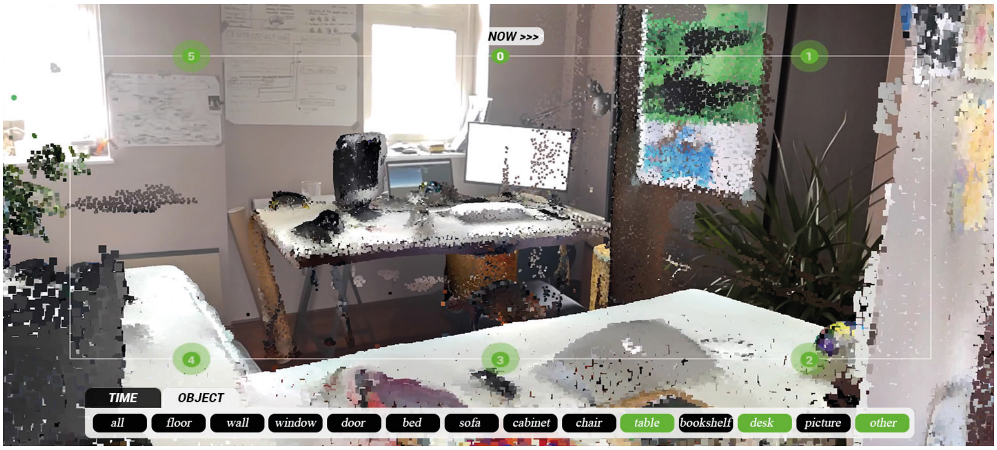

Fig. 10. The Object mode, where one can de-activate specific labels and view the equivalent objects on all time levels, with indications on the rectangle.

Source: Image from author.

Discussion

There is a growing availability and interest in developing spatio-temporal archives of PCLs as a means of preserving memories of the built environment and providing users with immersive experiences. This research draws upon broader theoretical and methodological frameworks, aiming to contextually place the development of such a system and relate it to contemporary media culture. The concept of "prosthesis" by Stiegler (1998), suggests that technology is an extension of the human, creating a technological unconscious and shaping our perceptions and understanding of the world. In this context, technology is used to enhance one's spatial memory and expand the temporal dimension of space, perhaps better understanding the space and its past.

The framing of the "extended present" (Ernst, 2017), is expressed here as a "window" in space, allowing for a glimpse of what was here before; the smartphone interface, which allows one to access and experience past events as if they were part of the present. The use of geo-located XR, which incorporated temporal and spatial attributes, aims to enmesh one's sense of the present and be able to exist in and inhabit multiple realities. It comprises a dynamic archive tied to the present and at the same time augmented with information from the past. All steps of the system's development are enclosed, as a loop, in a smartphone interface, highlighting the personal character of space and the increased accessibility and protection of personal data, as the whole system can be kept private. The smartphone interface has limited hardware capabilities as well, which may reduce the spatial experience, in contrast to other hardware such as Virtual Reality headsets which can be considered more immersive. However, the focus here is not experience-based. In contrast, the research encompasses different directions, from the more technique-oriented, to the archival and theoretical, and finally towards the user-oriented side of the system. While user testing, which has been conducted during the development of the prototype, is undoubtedly a vital part of the latter, it is beyond the scope of this paper, which aims to give a deeper contextual background on archival systems and the human relationship with them.

Fig. 11. Extended reality interface: An interactive interface to communicate with the 3D archive.
Source: Image from author.

Conclusion

This paper explores how spatial memory can form an archive, through media traditionally used to represent space, and specifically 3D scanning. It builds upon a theoretical framing, equally important to the included methodology. Additionally, a prototype system is proposed to record, declutter, filter and communicate with spatio-temporal information. It is argued that human experience is enhanced through a smartphone (iPhone) interface by augmenting the present spatial configuration with the ones in the past. Part of the research's findings, considering the increasing availability of both hardware and software for volumetric recording, is the necessity of a system to manage 3D information due to its high complexity. A communication medium and specifically the smartphone, is crucial to allow for interaction with the information. In parallel to Stiegler's theory on the evolution of prosthesis, smartphones are the extension of a human's hands in contemporary media culture and an increasingly available medium. They are a complex apparatus which provide connections to embed meaning onto a surface and it is used for the whole loop of the system; from recording spatial information, to storing it and interacting with it. Namely, the iPhone interface is selected because it is used for other information systems such as social media applications, and it contributes to the sense of scale, having information attached to the physical reality. Scale, in this context, has a dynamic role, from 1:1 physical reality to the scaleless digital space and back to 1:1

XR. This progress of recording and processing data results in a loss of resolution, or even as framed here, loss in memory of space.

Scale is also defined here through the case study of a bedroom, but the process could be implemented in other contexts such as a museum, a construction site or even a natural environment; any kind of space where it's meaningful to preserve its visual dimension. An expansion of the system could be a network where spatio-temporal information is archived, from various personal smartphones. However, the main focus of the paper is the personal dimension of space and how we perceive and inhabit it through our tools.

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