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DARE

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INTRODUCTION

Welcome to this special collection of research papers, a testament to the power of collaborative thought and academic exchange, presented at the Digital Architectural Research (DARe) Conference. Hosted at the Faculty of Architecture at the Bialystok University of Technology, in the city of Bialystok, Poland, the conference attracted a diverse and intellectually robust gathering of international PhD students and experienced researchers. These academics came together with a unified goal - to discuss, learn, and inspire progress in the realms of digital architecture and architectural technology.

The event, designed as a platform for budding researchers, provided a space for these young minds to dissect, explain, and invite critique on their most focused academic explorations. The curated papers in this volume encompass a broad spectrum of subjects - from exploring the utilization of technology in architectural design, delving into the possibilities of rapid prototyping in architecture, to dissecting the use and advantages of Building Information Modeling (BIM) tools.

Academic exchange is a powerful tool, particularly for those in the early stages of their research careers. It provides a platform for testing hypotheses, refining research questions, and challenging existing paradigms. Opportunities to present, defend, and refine their research among a community of peers are invaluable experiences for researchers in the making. They serve as crucial formative steps, honing not just the specifics of the individual research projects, but also helping the researchers grow in their roles as academicians and experts.

Consider the game-changing impact of Computer-Aided Architectural Design (CAAD) systems on architectural design and construction, a recurring theme in our conference. CAAD has revolutionized architectural design processes, from the conceptual stage to the final construction documents. So many outstanding architectural structures, iconic in their design and construction, owe their existence to the creative application of advanced computer modeling software, an aspect of architectural design deeply explored in this conference.

This conference, at its core, was an exploration of the synergies between architecture and technology. Rapid prototyping, for example, has been a remarkable leap in architectural design and construction. By facilitating the swift creation of three-dimensional models, architects can more effectively visualize and modify their designs, improving both the aesthetic and functional aspects of their projects.

Meanwhile, Building Information Modeling (BIM) tools are reshaping the dynamics of architectural and construction processes. Providing a multi-dimensional approach to architectural design, BIM tools have not only streamlined architectural processes but have also improved collaboration between various stakeholders involved in the construction process. Several papers in this collection delve into the potential of BIM tools and their role in transforming architectural practices.

The profound ways digital technology is influencing architecture was a recurring theme throughout the conference. The intersection of these two domains is creating a new discourse in architectural studies, pushing us to rethink traditional architectural practices and embrace these novel tools and technologies. The conference, thus, served as an opportunity to delve into this narrative, exploring the potential challenges and opportunities this digital shift may bring.

In reading these papers, you will notice the emphasis on the crucial role of feedback in refining research. A unique aspect of the DARe

Conference was the focus on providing robust, constructive feedback to researchers. This feedback often influences the direction of the research, helping refine the research questions and adding new dimensions to the studies.

In conclusion, the papers included in this collection offer a comprehensive overview of the exciting intersections of technology and architecture. They witness the potential of technological advancements to revolutionize architectural practices. Each paper, unique in its focus and exploration, adds a distinct flavor to this academic feast. We invite you to immerse yourself in this intellectual journey, engage with the diverse perspectives offered, and join the conversation on the future of digital architecture.

Adam Jakimowicz, PhD, MArch,
DARe conference chairman & co-editor
Bartosz Śliwecki, PhD, MArch,
co-editor

DISCRETISATION DESIGN STRATEGIES: DISCRETE DESIGN METHODOLOGICAL CLASSIFICATION

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ABSTRACT

The discretisation process is a digitally emerging effort that aims to rethink and possibly remodel the whole production cycle in the context of an architectural process. This is accomplished by advancing the concept of discretisation in both computational design and actual physical assembly components. In one sense, discretisation can be used to generate a two- or three-dimensional volume, or it can be used to divide an architectural volume or surface into sections that are more easily managed. Discretisation, when viewed from a different aspect, is also known as the science of architectural components. Discretisation is a form of modularity that assumes new architectural possibilities are emerging as a result of digitally driven design processes. These processes are characterised by dynamic, open-ended, unpredictable, adaptable, and consistent networked transformations of three-dimensional structures. Discretisation also confirms that these new architectural potential options are a result of digitally driven design processes.

In this study, we present a categorisation system for discretisation-based design approaches that is based on the technique. Before providing a category for discretisation methods, this work first analyses, evaluates, and constructs case studies for previously published methods from the body of earlier research. In the second step of the process, a broad theoretical framework that is constructed on the categorization analysis is utilised. Because of the specifications and functions, these methods can be synchronised with and combined with various other parametric design strategies, such as panelising, subdivision, or generative design. Within each category, we present an overview of, and conduct an investigation into, the possible associations that exist between our discretisation definitions and the additional parametric parameters. This study concludes by presenting a variety of multiple design possibilities for each category, as well as a logical design technique, and then summarising its findings. This paper does not focus on any specific programme or tool in particular.

Keywords: #Discretisation, #Parametric_Architecture, #Generative_Design, #Digital_Architecture, #Algorithmic_Design

1. INTRODUCTION

Advances in digital technologies and automated systems in the 21st century have caused industries to quickly update their production methods using digital technology; however, it has long been believed that production chain optimisation is what accelerates technical advancement and the creation of newer, more innovative devices (Retsin, 2019a). Immediately after the 2008 financial crisis, which Carpo referred to as the “first digital turn” (Carpo, 2017), digitality in architecture was linked to problematic neoliberal ideology (Retsin, 2019a). Discrete design techniques and algorithms have also been used more recently, during what Carpo refers to as the "Second Digital Turn," by architects working directly with computers (Carpo, 2019). Sometimes, the intention of design, art, and architecture is to create innovative, complicated, or aesthetically beautiful geometries that can be able to meet particular practical requirements (Klemmt, 2019). The use of digital planning techniques has enabled a level of creative freedom that was previously unachievable (Manahl, 2012).

The discretisation process is a digital emerging work that attempts to rethink and maybe remodel the entire production chain in an architectural process by pushing the idea of discretisation in both computational design and physical components of assembly (Retsin, 2019b). Although architectural decisions are occasionally made for aesthetic reasons, which has the obvious disadvantage of limiting the potential for performance enhancement (Wang et al., 2006), discretisation as a functional process can fulfil the requirements for both practical needed functions and aesthetic design (Zawidzki, 2017). In exchange for "scalability," "impact," and "agency," the discretisation is willing to re-evaluate building production while sacrificing a tiny portion of "resolution," "formal distinctiveness," and "excitement" (Retsin, 2019a). Discretisation is also willing to swap out delicate but scholarly material optimisation for huge volumes of inexpensive materials in order to increase accessibility and efficiency (Retsin, 2019a).

Overall, discretisation is the conversion of continuous equations, models, variables, and functions into their discrete equivalents. By breaking down the complicated geometry into manageable roles and relations, discretisation as a step-by-step design process could reduce the geometrical complexity (Jonas, 2014). In one sense, discretisation can be employed to divide an architectural volume or surface into smaller, constructible pieces (Manahl, 2012) or to form a 2D or 3D volume (Kaijima and Michalatos, 2007).

As Restin describes, discretisation can also be referred to as the science of architectural components (Retsin, 2016a). According to this viewpoint, discretisation can introduce new design characteristics. In discretisation, for example, the design process can begin with the module rather than the whole geometry. This feature provides the designer with sufficient flexibility and additional opportunities to explore far deeper into the relationships between building components as flexible, general, and even re-usable modules (Köhler and Hilberseimer, 2016). These two points of view allow for the categorization of discretisation methodologies into two distinct groups: top-down and bottom-up, which are distinguished by the direction in which the design process is carried out and the starting point (Zamani and Dounas, 2022). According to the concept of discretisation, which is a type of modularity, new architectural possibilities are developing as a result of digitally driven design processes that are characterised by dynamic, open-ended, unpredictable, versatile, yet consistent networked transformations of three-dimensional structures (Kolarevic 2000). When we approach at building blocks through the perspective of such specifications, we start to move the emphasis away from thinking of building elements as being unique to their purpose and toward an architecture made up of a defined collection of parts (Claypool, 2019).

2. METHODOLOGY

This paper uses inductive research method which involves drawing conclusions from observations and experiences, rather than starting with a preconceived hypothesis. This includes field studies, case studies, and literature review, where we gather data through develop theories and design principles. The information gathered through inductive research can then be applied to the new designs that are more linkable to the smart fabrication machineries. From this data, this study identifies common themes and patterns in the use of discrete design strategies, such as the specific geometric shapes or forms generated, the design algorithms they are applied to, or the design outcomes they produce, or even tools or specific software. The first part of this paper provides an overview of the development of discretisation methods and provides critical commentary on their relative strengths. These evaluations highlight and identify each case study's parametric logical and algorithmic requirements. The second phase involves categorising the techniques based on the logic of their designs and their conceptual and practical differences.

This study, moving toward a taxonomy for discretisation methods based on their numerous capabilities. This classification provides a full foundation towards a deep methodological understanding of existing discretising approaches in architectural design with the intention of generalising these methods for a wide variety of forms while at the same seeking for digital characteristics and requirements that could potentially be used to integrate digital design and fabrication. The gathered information may then be used to develop more progressive design principles and guidelines for using discrete geometry in architectural design, which can then be used in the development of new design strategies or even more innovative tools.

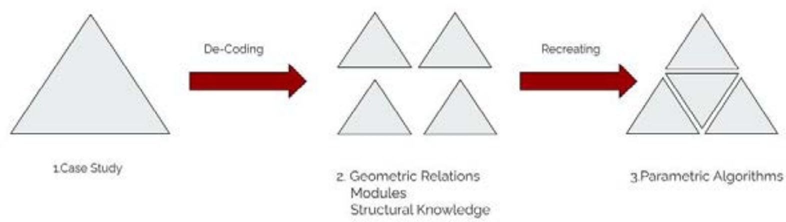

Figure 1 This study first explores a number of discretisation case studies from the literature and constructed structures, and then re-examines their parametric design procedures and arranges their algorithmic steps, credit by Erfan Zamani

3. STRATEGICAL FRAMEWORK

This paper establishes a theoretical framework for digital discretisation in architecture. While many discretisation approaches for architecture have been given at various scales, ranging from building modularity to urban planning, this work gathered digitalised ones to establish a theoretical foundation for digital discretisation. These approaches were classified based on the parametric logic that underpins them. The current work extensively investigated a number of discretisation approaches, whether through literature or prototype structures, in order to determine their parametric procedure. In the process of evaluating each strategy, the related ideas and approaches were also researched. Based on parametric procedural similarities and differences, digital discretisation approaches can be classified as follows. This work is a part of a broader study that aims to establish an integrated construction DfMA (Design for Manufacture and Assembly), from design through production.

3.1. Computational Growth

The computational growth through aggregating discrete parts in design, art, and architecture often strives to produce innovative, extremely complicated, or aesthetically stylish geometries, and even, generated geometries could be able to address particular functional necessities (Klemmt, 2016). The computational growth incorporates artificial intelligence into the design process through the use of exploratory search algorithms (Krish, 2011) and with its iterative progression towards a bigger accumulation of mass, allows for an equally repetitive evaluation of the geometry's current situation (Klemmt, 2019).

Many computer-based growth models, such as Cellular Automata (CA) and Diffusion Limited Aggregation (DLA), have been developed. To simulate growth processes, many part to whole-based mathematical logics have been applied. Although DLA was initially intended to operate in 2D grids, it is now frequently calculated in free form in 3D space (Witten and Sander 1981). There have been numerous attempts to employ them for architecture and urban planning (e.g., Al-Qattan, Yan and Galanter 2017). Also, Differential Growth in architectural design have been discovered comprehensively, in which individual cells can move in 3D space while they are typically structured as the vertices of polylines or of mesh surfaces (Klemmt, 2016). The resulted geometry can be used for digital arts or 3D-priting arts in different scales. Cellular Growth algorithms are utilised by Klemmt and Sugihara (2018), to build an installation out of tessellated sheet material. This research has been updated in (Klemmt, 2019) in which suggested algorithm is based on a 3D point cloud, with each module's centre being a point from the point cloud. modules are analysed and changed iteratively by shifting their positions, and if certain conditions are satisfied, a cell may even be divided (Klemmt, 2019).

Retsin (2016a, 2016b) makes additional arguments in support of serial repetition and assembly of discrete parts, based on volume and disintegration of the figure as opposed to surface and topology characteristic for parametric projects, highlighting the significance of part--to-whole interactions and the usage of elements that contain a certain type of design agency, where elements can respond to data such as stress, vector orientation, etc. Rossi and Tessmann (2017a,b,c & 2019) propose a spatial assembly method for discretised architectural formations. The parametric tool "WASP" underpins their growth-based 3D aggregation model. The final geometry's 3D contour defines a module's density boundary. This reversible approach integrates module shape complexity with geometry relationships and specifications. This method gives designers new manufacturing and assembly options and lets them manage or specify module attribution. Their new plugin WASP connects the discretised digital model to the real world. Tibbits creates an intelligent configuration framework concurrently (Tibbits, 2011). The boundary is aggregated by this self-assembling mechanism using intelligence blocks. Leder (2020) provides a method as coverage for non-standard concrete constructions with modules in the shape of a dodecahedron as another illustration of a modular aggregation configuration. This method can validate aggregation-based techniques and is quite adaptable in terms of overall shape design. The modules can be put together to create a closed form for casting concrete. Modules from this temporary building can be taken apart and reused. Dodecahedrons can be confined among numerous neighbours of the same shape due to their nature and the high number of sides, which provides more interface choices (Leder, 2020).

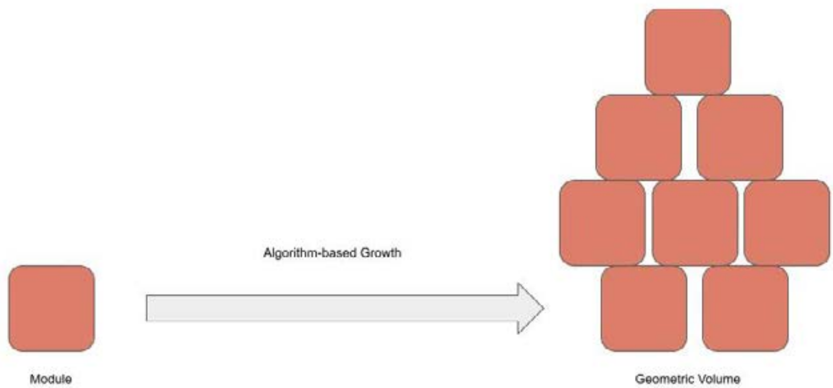

Figure 2 Computer-based growth, credit by Erfan Zamani

3.2. Subdivision Surfaces

The relationship between shape and production brings new challenges and requests for more complex underlying geometry (Pottmann; Helmut; Brell-Cokcan, 2007). Tessellation is the process of covering a surface with one or more geometrical objects without overlapping or gaps (Kizilörenli and Maden, 2021). By using modular shaping and planer surfaces beneath each shape, subdivision, as a parametrical tactic of tessellation, can be employed to approximate and discretise a geometry (Pottmann and Wallner, 2008). Pre-determined, repetitive defining and shaping of a discrete surface mesh defines subdivision surfaces (Liu et al., 2021). It also provides a parametric approach to modeling with developable and generative surfaces. Initially, this discretisation strategy, was targeted on discrete differential geometry, where R. Sauer (1970) demonstrated how discrete modules could be utilized to construct conjugate curve networks on surfaces. Theoretically, there is a strong connection between the limit surfaces of subdivision surfaces and conventional splines. The two phases in typical approaches are: dividing edges and adding vertices to make each input mesh element into multiple elements (one triangle becomes three, for example). Then, the locations of the mesh vertices are smoothed by averaging the positions of their neighbours using a weighting system that is only based on the local mesh connection.

According to (Hertzmann and Zorin, 2000), the fundamental principle of subdivision is to "define a smooth curve or surface as the limit of sequence of successive refinements." The earliest study on irregular polygon meshes had done by (Doo and Sabin, 1978) in which subdivision generates quad meshes. Quad meshes were the first attempts to approximate the modular shape to a surface. Authors in (Alliez *et al.*, 2003) describe how to compute quad-dominant meshes from smoothed primary curvature lines. Even though these meshes' faces aren't perfectly planar, one should assume that they are at least roughly so. According to (Cohen-Steiner and Morvan, 2003), variational shape approximation seeks to position a certain number of planar faces—which are typically not quadrilaterals—in the best possible location. The paper (Pottmann; Helmut; Brell-Cokcan, 2007) uses the same logic for conical meshes.

It demonstrates how to refine a quad mesh so that the mesh can even become conical or have its faces become planar.

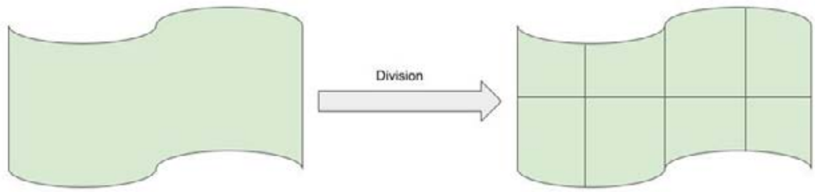

Figure 3 Subdivision logic, credit by Erfan Zamani

The study, (Liu *et al.*, 2020) proposed a non-linear neural subdivision system, based on the linear method of Loop (1987) for triangle meshes, which has attained a comparable level of popularity. A combinatorial update (split faces, adding points, and/or twisting edges (Kobbelt, 2000) and a vertex flattening (repositioning step) based on local average of surrounding vertex positions describe traditional linear subdivision algorithms. The availability, direct analysis, and continuity of the limit surface are thoroughly investigated from the standpoint of subdivision methods (Karciauskas and Peters 2018). A subdivision surface is often worked on by modellers in a controllable manner. The limit surface is typically visualised by most modelling tools, or at least a rough approximation of it, while the operator seeks to control the upper level (Liu *et al.*, 2020). Users can control the surface in addition to changing the vertices by including points or bent edges (Hoppe *et al.* 1994). Although noninterpolating techniques like Catmull-Clark or Loop seem to be the most common, interpolating techniques do exist and have similar smoothing guarantees (Dyn *et al.* 1990). However, fairness is more difficult to establish. In order to ensure smoothness, linear approaches are simpler to analyse and construct. As a result, the modeller or a predictable procedural function is charged with collecting details (Velho et al. 2002).

3.3. Cross Section

Polyhedral forms act as the foundation for the Moving Cross-Section Procedure approach (Kanel-Belov *et al.*, 2010). This systematic modular model consists of a network of planner square grids and polyhedron modules, where each square grid edge plays a key role in determining where the modules are placed. By specifying the side angle of the modules, this procedure can convert the plans into the modules (Pfeiffer *et al.*, 2020). Each square grid's pair the parallel sides defines the positions of the module's sides. This approach allows for the creation of polyhedron modules that are not predefined and work harmoniously with panner grids. Although the modules produced by cross-section are based on angle and pattern, they are still under parametric control. The dimensions and shape of the modules' sides can provide additional possibilities for interlocking joints (Pfeiffer *et al.*, 2020). Based on a planner network, the discretised sections can be topologically aggregated through cross-section.

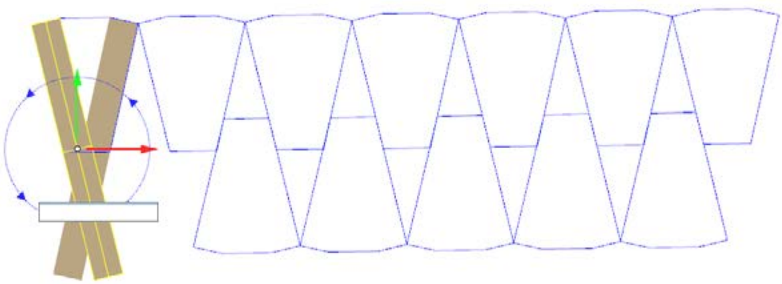

Figure 4 Cross-section, credit by Erfan Zamani

The Cross-Section approach creates a topological structure in which each module is surrounded by several neighbours, depending on the number of sides of the modules (Wang and Liu, 2009). X and Y motions should be avoided in the modules. Through the utilisation of computational design, analysis, and production techniques, the cross-section system can be re-defined inside a topological framework [e.g. (Tessmann, 2012)].

For instance, Bejarano and Hoffmann (2019) used a topological interlocking arrangement to expand Moving Cross-Section. Their configuration includes a repeatable assembly mechanism based on tasselling surfaces or mesh. The angular surfaces still contribute significantly, but Bejarano and Hoffmann add central point and height values that make the modular parametric control more flexible by analysing the structural behaviour of the modules. Rotation, motions, and slide to the front, rear, and sides are examples of these behaviours (Bejarano and Hoffmann, 2019). This method can be applied not just to regular curvature networks but also to develop geometrical shaping. For instance, Manahl (2012) presented a method for rapidly creating discrete meshes with planar faces that are specifically designed to approximate the intersection of tangent planes to the surface. The purpose of this geometric technique was to combine the processes of design rationalisation and form-finding. It was based on the intersection of tangent planes to the surface (Manahl, 2012).

4. CHARACTERISTICS FRAMEWORKS

This classification is based on the common procedural aspects of each technique. The current work attempts to encompass every relevant approach and to lay a solid theoretical foundation for discretisation.

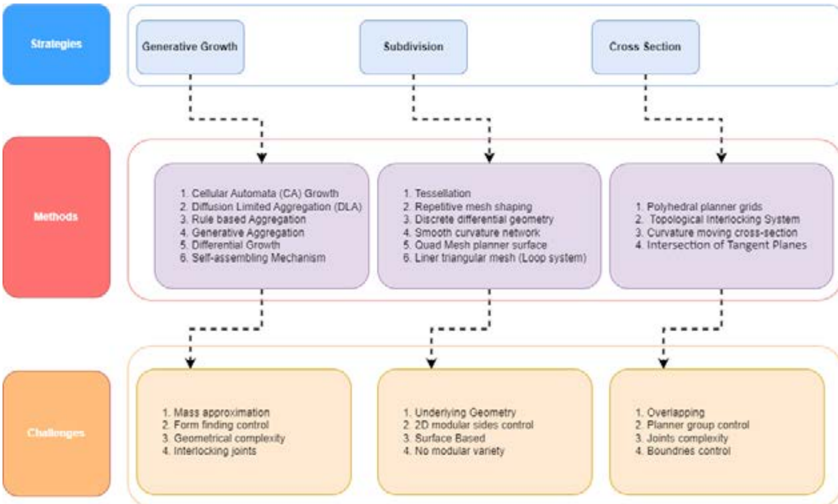

Figure 5 Discretisation strategical classification system, considering the methodological similarities and differences. credit by Erfan Zamani

4.1. Common Characteristics: Computational Growth

The emphasis in biology and medicine is on constructing models that precisely mirror real-life conditions, but the goal in computer science, particularly Artificial Life, is to design and comprehend processes that display life-like behaviours (Klemmt, 2019). A large number of modules are generated by algorithm-based growth. Depending on the method used, geometry approximation is still possible, but accurate geometry design is not. In addition, form recognition and 3D modelling are no longer different. Algorithms can influence the shape that is formed throughout the 3D modelling process. A growth simulation, with its iterative development towards a greater accumulation of mass, provides the opportunity for an equally iterative evaluation of the geometry's current state, which can then have an impact on the behaviours that direct the growth to develop towards a desired outcome, both globally and locally (Klemmt, 2019). Furthermore, this aggregation worked by combining the geometric representations and location data of a certain module, as well as by providing different algorithmic criteria for module data aggregation (Klavins *et al.*, 2004).

Figure 6 Growth-based discretisation is able to generate volumetric geometries. The generated shapes can have no boundaries (right), but setting the boundaries provides the designer better control over the aggregation process. credit by Erfan Zamani

4.2. Common Characteristics: Subdivision Surfaces

Subdivision Surfacing has a wide range of applications because subdivision combines discrete differential geometry, shape processing, and computational design (Pottmann; Helmut; Brell-Cokcan, 2007) to provide developable surfaces that can be projected onto the plane without distortion (Liu *et al.*, 2006). When combined with other parametric features, subdivision techniques can create volumetric geometry, which is extremely beneficial for free form design. Depending on the approach, sub-surfaces can be triangular, rectangular, or other shapes with more or isochronous slides. Certain approaches yield unique 3D modules because the sub-surfaces do not have the same shape and may or may not be regular.

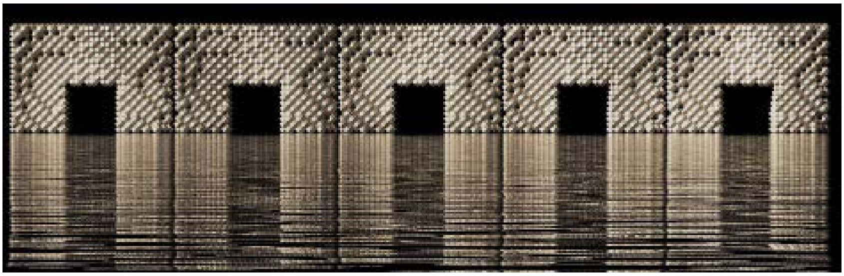

Figure 7 Subdivision technique by applying the voxel-shape modules to the surface. credit by Erfan Zamani

4.3. Common Characteristics: Cross Section

Cross Section develops a systematic modular structure that is organised and touches each neighbouring surface along a straight line by using planes. When subjected to appropriate boundary conditions, the assemblies are capable of withstanding higher bending loads and even tension without the use of an extra binder such as cement (Tessmann, 2012).

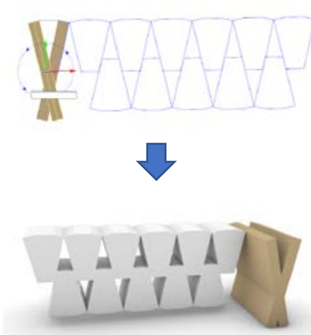

Figure 8 Cross section approaches can generate a repetitive network of modules, weather in one axis, two axis or even possibly in three axes, credit by Erfan Zamani

Moving Cross Section commonly known as the square grid with perpendicular planes on each edge. Picking an angle α, one of every two planes rotates around its particular edge by α, and the next one by -α. Thus, each square generates a tetrahedron, arranged so that it forms an interlocked grid. The square grid with orthogonal planes on each edge is commonly referred to "Moving Cross Section". One of every two planes spins about its specific edge by an angle α, and the following plane rotates by angle -α and as a result, each square becomes a tetrahedron, which is then placed into an interconnected grid (Weizmann *et al.*, 2015). However, this basic paving can be laid out in a variety of patterns, such as a hexagonal pattern that forms an interlocking grid of cubes or octahedrons (Pfeiffer *et al.*, 2020). But in methods like planner surface, even the grid network is not essential [e.g. (Manahl, 2012)] and sub-surfaces approximate on the main surface through a point or line.

Figure 9 Use of discretisation techniques for decoration design. credit by Erfan Zamani

5. FURTHER STUDY

The study that is being given is unique in that it deals with a classification for logical parametric discretisation. The research is important in that it establishes the necessity, limitations, and practical features of Discretisation and offers the toolset and a solid framework upon which production and assembly can be expanded. This study offers systematic categorization of Discretisation methods and emphasises parametric design technique as an effective tool for creative and intelligent creation. Different interlocking alternatives can be constructed for each suggested category of parametric logic. This possibility opens them fresh opportunities to present cutting-edge assembly techniques. A circular and dynamic process in which pre-programmed, computer-controlled machinery work alongside digital models and implementation simultaneously includes design and assembly. This research can be expanded to create structures that are particularly advantageous for robotic assembly. The assembly system can be validated by the proposed logical classification by looking at the joints and structural stability beneath the scale.

6. CONCLUSION

Discretised designs are made up of individual elements that can be modified, rearranged, or scaled independently of one another. This allows for greater flexibility in adapting the design to different site conditions or design requirements, such as changes in building code or zoning requirements, or accommodating topography. This can be especially useful in cases where the design needs to be adapted to fit the specific needs of a particular site or client. Discretisation allows for the use of computational algorithms to design and optimise architectural forms based on specific design criteria, such as structural performance or modularity. This allows for the exploration of a wide range of design options in a relatively short amount of time, which in perspective can greatly increase the efficiency of the construction process.

Automated fabrication processes, such as CNC milling, 3D printing, or robotic fabrication, can also greatly increase the efficiency of the production chain. These techniques can be used to fabricate discrete elements with high precision and accuracy and can be easily integrated with parametric design tools. This can greatly reduce the amount of time required to fabricate the final structure and can also reduce the cost of fabrication by minimising the need for manual labour. Additionally, this can lead to improved performance and durability of the final structure because the discrete elements can be fabricated to precise tolerances and assembled with greater accuracy.

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THE CONFLICT BETWEEN MODERN AND HISTORIC IN ARCHITECTURE CONTEXT

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ABSTRACT

Everything changes rapidly all over time. However, Cities are still the witness place that tells us more about cultural, historical, and material. In this regard, Architecture plays a significant role, especially, when the new meets or combines with that have been built already or when architects try to merge the new and the old.

Historical buildings seem like an artery of cities, providing a deep insight into the culture, traditions, and values and what life was like. It is hard to imagine a city; without historic buildings, historic districts, and areas with a special importance value of its buildings in such areas because it is representing a significant cultural heritage for the city and its people.

The new and the old together may strengthen each other. oftentimes, the new architecture blended with its old neighbors and on the

other, it may conflict with the existing. This research will discuss the topic of modern architecture and How can integrate the new in historical places? Specifically, it looks at how to combine simplicity and complexity in Old places and their existing response.

Keywords: Architecture-Heritage-Historical Places -Preservation-Modern Historical Buildings

1. INTRODUCTION

Cities are still the witness place that tells us more about cultural, historical, and material. While Historical buildings seem like an artery of cities, providing a deep insight into the culture, traditions, and values and what life was like in the past. It is hard to imagine a city; without historic buildings, historic districts, and areas with a special importance value of its buildings in such areas because it is representing a significant cultural heritage for the city and its people.

The preservation of culture and heritage for future generations is the responsibility of everyone from the degradation processes, which are brought on by environmental factors, erosion, destruction, and other factors. As cultural heritage is considered the most crucial aspect of contemporary society and the most important component of identity in the modern era[1].

The new and the old together may strengthen each other. Along with historical buildings, build of new attachments takes place, Sometimes, these new attachments may correspond with their old neighbors, and on the other, they may conflict with the existing ones. Which in most cases do not match the stylistic features of historical buildings and distort the urban historical fabric of cities. The aim of this research is to discuss the topic of modern architecture and How can integrate the new in historical places? Specifically, it looks at how to combine simplicity and complexity in Old places and their existing response throught analysis criticism and comparison . In this light, Several examples have been selected and criticized through international guidelines and charters of preservation.

2. GUIDELINES AND CHARTERS FOR NEW DESIGNS IN A HISTORIC CONTEXT

The idea of compatibility is frequently taken into account when deciding where to place new construction within a historic district. In architecture, compatibility refers to design features and characteristics that help create a visual and aesthetic connection between old and new.

The aim of compatibility is to find the distinct design components that, when used, will create harmony and balance between the new and historic architectural styles [2]. In the discussion of fusing the new and the old, the following compatibility factors are taken into account:. Size, Scale, Color, Proportion, Material, Character, Solid vs void relationship and Compatibility within the district, sub-area, or block. There are several other ways to look at the integration of new and old according to Steven W. Semes associate professor at the University of Notre Dame School of Architecture. He stated that there are four strategies when designing a new building for an existing historic setting:

- Literal replication
- Invention within the same or related style
- Abstract reference
- Intentional opposition

While Carbonara stated that there are three key factors of restoration: a) the history of architecture and theory of restoration; it includes the know how of maintaining a building's original character and structure b) the techniques of survey, analysis, diagnosis, and interventions on the materials and the structure; it includes the restoration code and regulations and ensuring materials and methods are compitable with the time period c) legislative and regulatory aspects it contains contacting local, state, and federal boards of historic preservation to integrate their rules, regulations, and guidelines [30].

Besides, there are international preservation standards and charters for new designs in a historic context that could be summarized as the following:

- Replacements for missing parts have to integrate harmoniously with the whole old design while still standing out from the original.

- Additions are not permitted unless they do not interfere with the architecturally interesting features of the building, its historic setting, the composition's balance, or its relationship to its surroundings.

- Only insofar as proper consideration is given to the appropriate use of mass, scale, rhythm, and appearance will such contemporary architecture, which makes deliberate use of modern techniques and materials, fit itself into an ancient setting without impairing the latter's structural and aesthetic qualities.

- The authenticity of historical monuments or clusters of buildings must be considered as a fundamental criterion, and any imitations that would detract from their artistic and historical value must be avoided.

- Urban development or slum clearance programs involving the removal of structures with no architectural or historic significance that are structurally unsound and cannot be preserved, the removal of additions and additional storeys of no value, and sometimes even the demolition of more recent structures that disrupt the cohesiveness of the area, may only be authorized in accordance with the plan where safeguarding plans exist.

- Regulations and oversight of new construction should be given extra attention to ensure that their architecture blends in harmoniously with the setting and spatial organization of the groups of historic buildings. To achieve this, any new construction should be preceded by an analysis of the urban context, not only to define the general character of the group of buildings but also to analyze its dominant features, e. g. the harmony of heights, hues, materials, and forms, as well as the principles that govern the construction of facades and roofs, the volume of buildings in relation to the volume of space, as well as the average building sizes and locations. The size of the lots needs to be paid special attention because any reorganization of the lots could result in a change in mass, which could be detrimental to the harmony of the whole.

- Changes that lessen cultural significance should be reversible and should be done so when the situation allows. Reversible modifications ought to be regarded as transient. Only in extreme cases and not to stop further conservation efforts should irreversible change be used.

- Insofar as they do not obscure or distort the location's cultural significance or take away from its interpretation and appreciation, new work, such as additions to the site, may be acceptable. If the placement, bulk, form, scale, personality, color, texture, and material of a new piece of work are similar to those of the surrounding structure, it may be sympathetic; imitation should be avoided.

- Making decisions about interventions and modern architecture in a historic urban setting requires careful thought, sensitivity to cultural and historic context, stakeholder consultations, and technical expertise. Such a procedure enables appropriate and proper action for specific cases, while respecting the authenticity and integrity of historic building stock and fabric. It also examines the spatial context between old and new.

- Generally speaking, proportion and design must fit into the specific type of historic pattern and architecture, and removing the most important parts of the building stock that should be preserved (façadism) does not constitute an appropriate method of structural intervention. In order to preserve the historic character of the city, special care should be taken to make sure that the development of contemporary architecture in World Heritage cities complements the values of the historic urban landscape and stays within bounds.

3. HISTORIC AND MODERN ARCHITECTURE

These new architectural additions could convert the city into significant landmarks or may harm the originality and value of the heritage buildings of the city[4]. There are many examples of Historic and Modern Architecture coming together. When historic and modern architecture is joined together in a thoughtful manner especially when it takes place in historically sensitive contexts, the results can be splendid. Several examples are proof that such as:

A. Museum of Military History, Germany

Architect: Daniel Libeskind
Location: Dresden, Germany
Date of adding: It completed in 2011

Figure 1: Museum of Military History, Germany. Source: https://www.dezeen.com/

The aim of building design is to boost the contrast between old and new. The architect said *"It is about the juxtaposition of tradition and innovation, of the new and the old."* The new addition of triangular to the old building creates a strong contrast and the architect stated that it was necessary to emphasize the shift in the museum's identity through a drastic intervention that shows an otherwise traditional neoclassical building[5]. The addition is in the form of a glass, steel, and concrete wedge that meets with the facade of the previous armory constructed in the 1870s. It also expresses the destruction and pain caused by the second world war.

B. Dancing House (Prague, Czech Republic)

Architect: Vlado Milunić and Frank Gehry
Location: Prague, Czech Republic
Date of adding: 1996

Figure 2: Dancing House ,Czech Republic. Photo: Oscar Gonzalez

The building has a restaurant, offices, and a museum located inside of these swaying cylinders, known as "The Dancers," which were created in 1996. In the historical city of Prague, The Dancing House has been deemed inappropriate. Some have criticized the dynamic structure for standing out among the city's many Baroque, Gothic, and Art Nouveau structures despite the fact that it is surrounded by 18th- and 19th-century structures. The deconstructivist design is divisive because it interferes with Prague's famed Baroque, Gothic, and Art Nouveau structures. However, it considers one of the city's most unique and tourist attraction buildings.

C. City of Fashion and Design (Paris)

Architect: Jakob + MacFarlane
Location: Paris
Date of adding: 2008

Figure 3: City of Fashion and Design ,Paris Photo by:Alamy Stock

In contrast, The building was constructed inside old general storehouses on the Quai d'Austerlitz in Paris. The ultracontemporary, bright-green building on the site's exterior has transformed what was once a location without much personality[5]. It is also considers one of the most remarkable contemporary monuments of Paris with its bold architecture.

D. Sant Fransesc Church (Santpedor, Spain)

Architect: David Closes
Location: Santpedor, Spain
Date of adding: 2011

Figure 4: Sant Fransesc Church,Spain Photo: Jordi Surroca

The intervention strengthened the church without erasing the deterioration and collapse that the structure had suffered. It has simply strengthened the old fabric distinguishing clearly the new elements executed of the original ones. Without sacrificing the use of modern language in the new components added to the intervention, the renovation work allows us to read historical scars and the building's most significant spatial values. The intervention protects the historical heritage of the building while also bringing new significance that elegantly highlights and singularizes the old church.

Table (1): Evaluation of previous examples according to the international preservation standrards and charters

No.	Conservation guidlines	Museum of Military History, Germany	Dancing House (Prague, Czech Republic)	City of Fashion and Design (Paris)	Sant Fransesc Church (Santpedor, Spain)
1	The new addition has to be a harmonious integration with the other parts.			•	
2	Additions must be differentiated from the original	•	•	•	•
3	Additions should be compatible with the heritage building and its traditional contexts.	•		•	•
4	A balance between old and new in the composition	•	•	•	•
5	Material, mass, scale, color, and proportion have to be harmonious with the existing fabric and historic character		•	•	•
6	The new addition should fit with the structural and aesthetic characteristics of historical buildings and their context			•	
7	Changes that lessen cultural significance should be reversible and implemented only under certain conditions	•	•		•
8	The integrity and authenticity of the historic fabric and building stock should be respected by new additions			•	•

Finally, Each generation contributes to the constantly evolving historic environment in its own way. Architects, building designers, and developers are crucial to the outcome of such change[7]. They have a responsibility to future generations to ensure that their contributions enrich, rather than diminish, the environment. They must comprehend the significance of a place and respond to it. Heritage items are a response to their cultural, social, historical, political, economic, and physical environments.

4. CONCLUSION

The design approach of new additions is one of the most important issues that have to argue especially in the heritage and conservation field. New additions have to be different but compatible to achieve harmony between new and historic and their context in order to prevent restoration from falsifying the artistic or historical evidence,. New architectural designs ought to add valuable value to heritage buildings instead of destroying their character and identity. Therefore, these additions can be acceptable if it adds to the city's identity and if it does not damage the existing historic identity.

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CLAY NON-PLANAR PRINTING OF OVERHANGS

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ABSTRACT

While the CAD model is being prepared for 3D printing, it is sliced into layers. Contrary to planar slicing, where an object is cut by horizontal planes and then a curve for the toolpath is generated from these intersections, non-planar slicing uses twisted planes for object cutting. It brings freedom to toolpath creation and each object can be printed in adjusted layers that reflect its geometry. Benefits of such printing are being explored in plastics and involve enhanced surface finish, cracking reduction and ability to print cantilevers. This paper examines printability of overhangs using clay non-planar printing. Basic potter‘s clay, from an art supplies shop was mixed with additional water and let in room temperature for one day. Desktop FDM delta printer was retrofitted with a clay printhead, its extruder motor was geared into a 19:1 ratio and connected to the ram. This ram pushes clay from a tank and nylon tube through a 4mm thick nozzle. Set of vase-like objects was designed, each with a different overhang. Starting at 10 degrees and ending at 70 degrees,

in increments of 5 degrees. Objects were modelled in Rhinoceros software and G-code for both planar and non-planar print was generated in Grasshopper. Each of those objects were printed twice, once planarly and once non-planarly. During the printing buckling and collapsing of printed objects was monitored. Non-planar printing improves buildability and reduces deformation of overhangs. Right after the print and after they got dry, objects were measured for their deformation. Shrinkage during the drying was measured to be 12,5%. Ideal toolpath for non-planar printing seems to be the one having layers perpendicular to the overhang. Model evaluation and non-planar printing data preparation is being discussed in the paper. If used on a large scale, non-planar printing may allow printing walls with holes for plumbing, or even printing vaults or bridges.

Keywords: additive manufacturing, non-planar printing, clay, overhangs, slicing method

1. BACKGROUND

3D printing is a rapidly evolving technology that has the potential to revolutionise the way we design and manufacture objects (Huang, Y. et al. 2015). Its key advantages are rapid prototyping, savings of material and at construction sites it can reduce the amount of workers, making a safer work environment (Kim, M. et al. 2015). One of the topics in 3D printing is how to achieve a high-quality finish on the surface of the object while maintaining, or even improving its structural integrity (El-Sayegh, Set al. 2020). The traditional method of 3D printing, known as planar slicing, involves slicing the 3D model into horizontal layers and printing each layer one by one. However, this method has several limitations, including poor surface finish and increased susceptibility to cracking. Sloping surfaces are printed as steps of increasing layers with typical "stair-stepping effect". Which can be reduced by lowering the print layer, or by rotating the object on the print base (Delfs, P. Et al. 2016). If the increment between two layers is too big, the object starts to deform and eventually collapses. Printing of overhangs, cantilevers and vaults is limited. While using plastic, it is possible to print extra support construction out of the same material, which is later removed. Printing support during the concrete or clay printing is limited and requires postprocessing (Tay, Y. 2019).

Non-planar slicing is a newer method that involves slicing the 3D model into non-horizontal layers with varying layer heights. This technique has been shown to have several benefits over planar slicing, including enhanced surface finish, cracking reduction and the ability to print cantilevers (Perreault, D. 2019), (Ahlers, D. and Zhang, J. 2018), (Shembekar, A.V. et al. 2018), (Cendrero, A.M. et al. 2021), (Shembekar, A.V. et al. 2019), (Alsharhan, et al. 2017). One of the earliest presenters of plastic non-planar 3D printing was James Page, who made in 2014 a video of plastic non--planar printing on top of an earlier printed curved base (Page, J. 2014). Most non-planar experiments are still centred around plastic printing.

Printhead construction of desktop printers limits use of non planar printing, because print head components may bump into printed objects, the nozzle may scratch an already printed layer. This problem is mapped in a master's thesis by Daniel Ahlers (Ahlers, D. and Zhang, J. 2018). To unfold the full potential of non-planar printing at least a 4-axis printer has to be used. A 6-axis industrial robot was used to print out of plastics a horizontal beam, without support (FreeD 2022). Contrary to plastics, clay´s long drying period causes that the whole object is still soft after the end of printing. Drying should take at least 24 hours to lessen the risk of cracking (Stirling, R.A., et al. 2017). Forced faster drying may be implemented by blowing hot air on the printed object (Keep, J. 2020), but it reduces final quality of the object and increases risk of cracking (Musielak, G. and Śliwa, T. 2015). Although drying time of clay limits possibilities of non-planar printing, it may theoretically offer improved surface finish, modifications of the object´s anisotropicity, reduction of cracking, inner forces may be guided into layers instead of their connections and to print larger overhangs. This technique has not yet been widely explored in the context of clay or concrete printing. There are several projects (Schipper, R. et al. 2017), (Li, S. Et al. 2023), (Naboni, R. Et al. 2022) experimenting with printing on non-planar bases. Or using this technique to achieve complicated vault pieces out of concrete (Vertico 2022).

In this paper we report on our experiments with non-linear 3D printing. We print a series of small objects in the size range of 8cm height using both planar and non-planar slicing; while varying the angle in non--planar slicing.

2. METHODOLOGY

Rigidity of each printed object is determined by layer-to layer adhesion. This interlayer bond is often weaker than the layer itself and under the shear stress cracks appear alongside bonds of subsequent layers (Hager, I. et al. 2022). When printing clay, layers may slide on top of each other, especially if you are printing overhangs. This causes bending and eventual collapse of the object. Goal of our experiment is to improve clay buildability of large overhangs by specifically designed non-planar layers that guide bending moment into layers itself, therefore reducing stress formerly directed to the layer bonds. Non-planar layers also decrease the stair stepping effect. To test our hypothesis, we decided to design a set of vase-like objects, each with a different overhang, as shown on Figure 1. Starting at 10 degrees and ending at 70 degrees, in increments of 5 degrees. All of them have the same overhang on both sides in order to keep their centre of mass at the centre of the base. Each object was sliced planarly and non-planarly (Figure 2). Both slicing methods are set to have the same amount of layers, similar printing time and amount of deposited material. During the print we observed buckling and collapse of layers. When layers started to fall down on both sides of the object, we aborted the print. Successfully printed objects were measured to analyse their deformation.

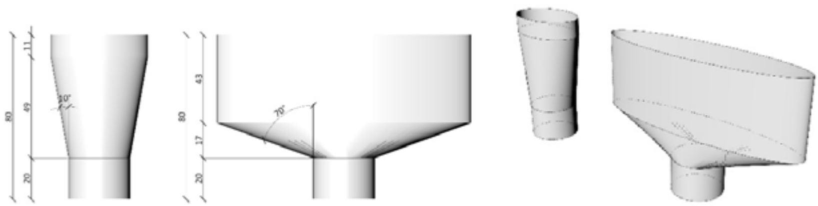

Figure 1: Front and perspective view of vase-like objects with overhangs 10 and 70 degrees.

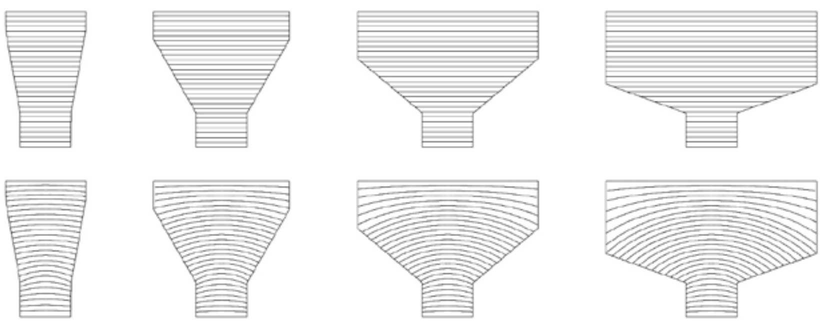

Figure 2: Top row displays planarly sliced objects and bottom one non-planarly sliced ones. Overhangs of 10, 30, 50 and 70 degrees are shown.

3. SETUP

Potter‘s clay THE Svída (ref) was chosen for the experiment. Stated shrinkage of the material is 7% during the drying and another 6% during the firing. Because we added more water, we experienced a greater shrinkage of 12,5% after the drying. None of the objects were fired, so shrinkage after the firing was not measured. 1 kilo of clay initially contained 190 ml of water, with water-to-clay (w/c) ratio of 0.19. To make this material printable a higher w/c ratio was needed. By preliminary experiments we determined the optimal w/c ratio to be 0,37. All further printing sessions are done using clay this w/c ratio. Mixed clay was left in a bucket for 1 day to let water dissipate equally.

Before printing clay was loaded into a custom tank with a mechanical ram. Motor of the ram is connected directly to the extruder stepper driver of the printer. Nylon tube with an inner diameter of 10mm delivers material into the 4 mm nozzle. Nozzle is 5 cm high, to prevent printhead bumping into already printed non-planar layers. Printhead is a simple tube to nozzle converter, without any additional de-airing or mixing system. Using these systems would improve print quality and reduce risk of bubbles destroying print (Chaari, M.Z. et al. 2022), however our modified FDM delta printer (Figure 3) used for this experiment was not capable of carrying any extra weight on the printhead.

To prevent objects from buckling and collapsing, additional heating and air blowing was introduced. One small heat blower and two 24V 10 cm fans were used to dry printed clay objects faster. All were placed 50 cm away from the printer. By having them closer we would risk tipping printed objects by the strength of the blown air. Using a heated bed is also an option, but we were printing on pieces of cardboard, which did not transmit enough heat. All modelling, slicing and G-code creation was done in Grasshopper.

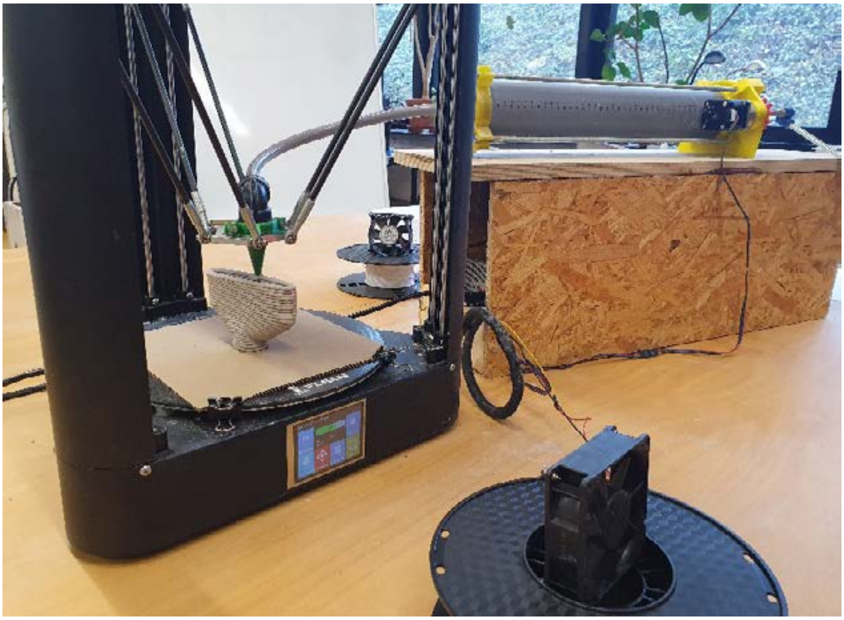

Figure 3: Clay printing setup composed out of delta printer, custom clay tank with ram extruder and drying system using fans.

4. NON PLANAR SLICING WORKFLOW

To achieve non-planar slicing we used Grasshopper script and set straight lines at the bottom and at the top of the object plus one curved line in the middle of the object. Tweening those lines resulted in non-planar lines with straight bottom and top layer. By projecting these lines on top of the surface we got printing contours. Due to its varying height, the extrusion multiplier has to change as well. Multiplier should be changed slightly in advance, because of ram extruder reaction latency. We also tested changing the speed of the printer, but during the printing of low layers with a small amount of deposited material the printer moved so fast and clay was not properly deposited. Combination of both methods proved to be reliable. While extruding very little clay, the printer moves faster with a small extrusion multiplier and when a large amount of clay has to be deposited, the printer moves slower, with a high extrusion multiplier.

Initial idea behind using non-planar layers was to increase resolution at the overhangs and decrease stair stepping effect (Figure 4). After preliminary testing, non-planar objects got printed unexpectedly well and further examination indicated that such organisation of layers reduces sliding of subsequent layers and guides inner force perpendicularly to bonds of layers. Therefore we assume that best layer organisation would be perpendicular to the overhang. But that would create very steep slopes of material, which would be scratched by the nozzle of our 3-axis printer. With a 6-axis robot capable of tilting the nozzle it would be possible to print layers perpendicular to the overhang and test this assumption.

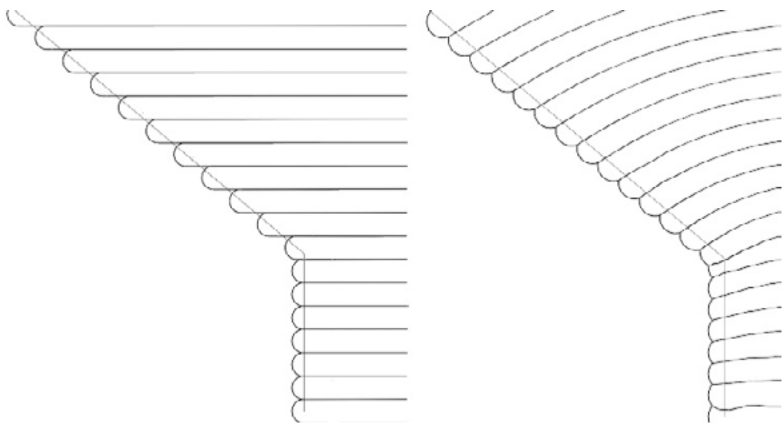

Figure 4: Detail of overhang sliced planarly and non-planarly with increased amount of layers and higher precision at the overhang.

5. 3D PRINTING

All vases were printed by 4 mm nozzle, with final wall thickness of 8 mm and average layer height of 3 mm. Non-planar printing layer height varied, with extremes of 1,5 to 6 mm. Print speed was most of the time 8 mm/s, at points of extreme height of layers, speed decreased to 6 mm/s. Due to having only a 3-axis printer, we could not tilt the nozzle, so at steep layers, the nozzle scratched printed material and collected part of the clay on itself. This clay dried and further scratched the top layer. At some point it detached from the nozzle and remained inside the print as a bump (Figure 5).

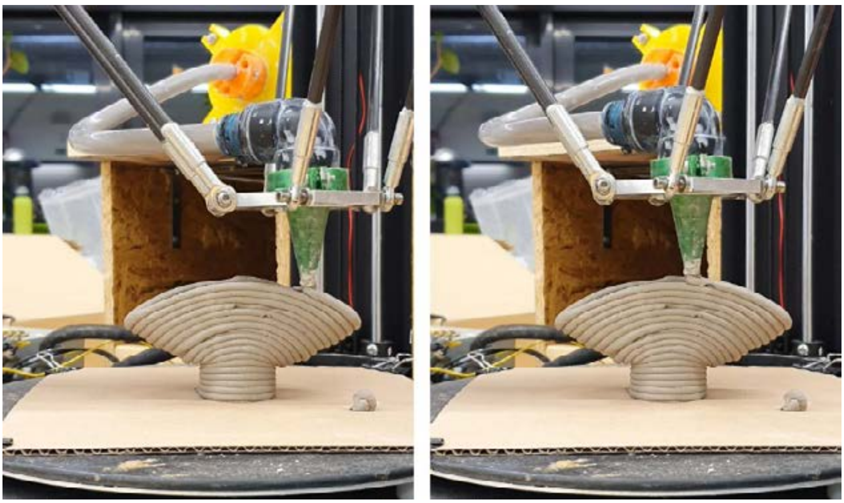

Figure 5: Detail of non-planarly sliced vase with an overhang of 65 degrees. At steep slopes the nozzle scratched the clay and excess material accumulated at the tip of the nozzle. At some point it detached from the nozzle and remained inside the print as a bump.

Overhang of 55 degrees appears to be maximum for planar printing. At 60 degrees (Figure 5), one side started to collapse and layers were falling onto the print bed. Other side did not touch the ground, so we printed the whole piece. At the end of print it slumped and touched ground on both sides. Further on planar print was stopped right after layers on both sides started falling onto the print bed.

Figure 6: Planarly sliced object with an overhang of 60 degrees. Layers at the bottom slid down during the printing into curved layers similar to ones we used for non-planar slicing.

Non planarly sliced objects proved to be more resilient at the overhang part, but at the top part, where layers should become flat another issue occured. Top layers were so thick, that the amount of deposited clay on one side skewed the centre of mass and the object started to bend on the side, where printing was happening. At some tests this bending from side to side caused object to fall. After the successful printing of a non-planarly sliced vase with 70 degrees overhang, we created another model, with 80 degrees overhang. During the printing overhang did not collapse, but slightly dropped and we had to stop printing at the final layers, because large amount of material deposited on one side threatened tipping the object.

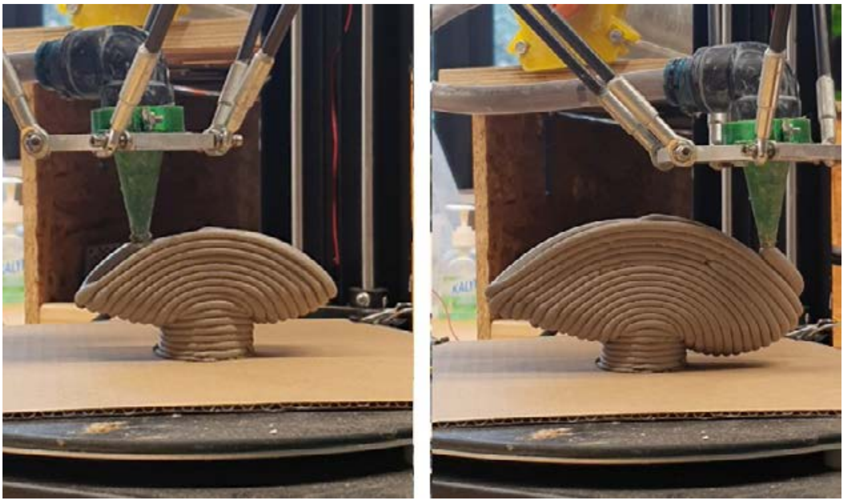

Figure 7: Non-planar printing of the object with 80 degrees overhang.

6. RESULTS:

Planar prints started to deviate from the 3D model at 45 degrees, where first layers of the overhang, right above the base, started to slump and bent into non-planar like curves. Object with 55 degrees of overhang was the maximal successfully printed, later ones were collapsing.

Non-planar prints managed to withstand printing of overhangs up to 80 degrees, but then failed to withstand uneven weight of top layers (Figure 8).

Figure 8: Top row displays planarly printed objects and bottom one non-planarly sliced ones. Overhangs of 10, 30, 50 and 70 degrees are shown.

7. DISCUSSION

Non-planar printing allows to print bigger overhangs compared to planar one. Similar experiments should be done with objects prepared by adaptive slicing, where layers stay horizontal, but differ in height. It adds more layers at the part of the overhang and lessens the stair stepping effect. Non-planar printing also modifies anisotropicity of the object by changing the direction of interlayer bonds. Question how much non-planar printing modifies structural integrity and its behaviour under the strength test should be researched. Proper non-planar slicing workflow reflecting force flow needs to be developed in order to utilise potential benefits. Also 6 axis printers should provide better results compared to our 3 axis delta printer. More axis allows you to print perpendicularly at any point of the curved layer.

Printed objects were only 8 centimetres high and maximal overhang was only at a small part. It is necessary to continue testing it on a larger scale with a 6-axis robot. Cementitious materials with added accelerant, might benefit from using non-planar printing. By reflecting upon the last experiment with printing 80 degrees overhang, where material slumped to almost 90 degrees, it could be used to print vaults, ducts, but theoretically also window openings and beams. Printing would happen from each side of the walls (Figure 9). Curved layers would work as a vault system, distributing weight into the walls, which could also reduce later cracking around the openings.

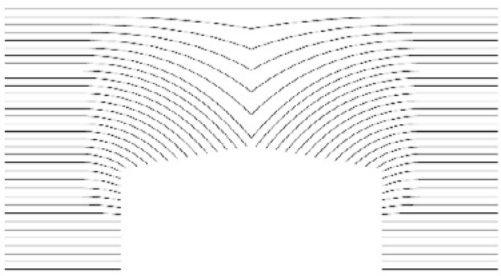

Figure 9: Non-planar printing of the object with 80 degrees overhang. By later slumping of not yet completely solid material, opening could theoretically reach near 90 degrees overhang.

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FOETAL, CHILD, AND ADULT PHYSICAL AND DIGITAL TWINS IN DESIGN PROCESS THROUGH HYBRID PROTOTYPES

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ABSTRACT

The digital twin concept is defined as a trio of physical counterparts, virtual counterparts, and their connections. A digital twin, which is used in many industries, can be a simultaneous reflection of a building and its design scenarios, digital versus physical or physical versus digital, in the architectural design realm. Specifically, our focus is on the built environment, where hybrid prototypes can use several sensors, actuators, and processors to simultaneously collect and react to data by applying digital twin technology while still in the design process. Hybrid prototypes extend physical models as we know them today with digital models supported by digital twin technology. The foetal digital twin is at the start of the concept design and can be in the form mainly of simulations or a physical scale model combined with some sensors. The child digital twin can be a door or window model, facade prototype, shading system mock-up, or wall prefabrication fitted with sensor technology. Here, we hypothesise that foetal and child digital twins may be appropriate stand-ins for adult digital twins through the design process. Therefore, we try to determine how we can have better foetal, child, and adult physical and digital twins. To accomplish this, we provide an architectural design catalogue that includes sensors during prototyping to guide designers. Sensor network establishment is one of the first tasks that can be performed for a digital twin. The sensed data from the physical prototype will be used in a digital twin to actuate and monitor the status, and the digital prototype will be used for the simulation, optimization, and prediction of future status. Eventually, data combination will be achieved with the help of Building Information Modelling and the Internet of Things. To guide the design process efficiently, it is important to decide where the sensors will be because, after the final design and operation, things will be handed over to a facility manager.

Keywords: Digital Twin, Design Process, Hybrid Prototyping, Foetal--Child-Adult Physical and Digital Twins

1. INTRODUCTION

In recent years, studies by Tao et al. (2018a; 2018b; 2020), Jones et al. (2019), Lydon et al. (2019), and Peng et al. (2020) have shown that Digital Twin (DT) have become increasingly used in design processes. This may be due to the increased use of advanced sensor technologies and computing (Qi et al., 2021, p. 3). DTs are virtual representations of real-world physical twins that can be used for simulation and performance analysis of the physical twin in different conditions during design (Grieves and Vickers, 2017, pp. 97 & 108; Tao et al., 2018a, p. 3567). DT has been used in the design process for existing product design processes from conceptual design, detailed design and production (Tao et al., 2018a; 2018b; 2020), pumping system, automotive wiring system (Jones et al., 2019), designing a thermal system for lightweight roof structure using sensor data and simulations (Lydon et al., 2019), and digitalization of a hospital project from concept to operation phases (Peng et al., 2020).

One of the key areas where DT technology is particularly promising is the development of hybrid prototypes (Jones et al., 2019, p. 2566). The hybrid prototype is a prototype enriched with DT technology and capabilities, that is, the physical models are equipped with sensors that are fed live to the design model, combining the physical and digital models (Emir Isik and Achten, 2022b, pp. 53 & 56). In the non-DT study, Kim (2019, pp. 7-10) emphasises that by including sensors in these hybrid prototypes, it is possible to collect real-time data on the performance of the prototype and use this data to improve and optimise the architectural design. Digital models can be used to provide significant cost and time savings for design optimization and efficiency of the physical results (Lo, Chen, and Zhong, 2021, p. 1; Lehtola et al., 2022, p. 1). Within digital-physical model integration, designers can identify and resolve issues early in the design process (Jones et al., 2019, p. 2566).

Just like prototypes evolve in the level of detail and elaboration during the design process, hybrid prototypes will do the same. We base our work on the useful distinction by Sacks et al. (2020, p. 16) who use the terms *foetal, child,* and *adult digital twin.* The physical and digital twin lifecycle so-called foetal, child, and adult twin are considered to be physical models, prototypes, mockups, or prefabrication by Emir Isik and Achten (2022a, p. 52; 2022b, p. 56). In this case, we hypothesise that foetal and child DTs may be suitable stand-ins for adult DTs through the design process. As a result, we try to determine how to apply foetal, child, and adult physical and digital twins. To this end, we provide an architectural design catalogue that includes sensors during prototyping to guide designers.

We examine the various benefits and challenges of this approach and discuss what designers take into account when implementing DTs in their work. To achieve this, this paper is divided into the following parts: (2) relevant background of digital twin and physical twin; (3) hybrid prototypes and digital twin; (4) foetal, child, adult physical and digital twin; (5) digital twin technology and IoT integration; (6) conclusion.

2. PHYSICAL AND DIGITAL TWIN

The digital twin is constructed as a selection of relevant features of the physical twin (Grieves, 2019). For example, it can be perceived as data sent to the digital twin as seen, heard, touched, or smelled in architectural buildings (Emir Isik and Achten, 2022a, p. 49). The digital twin is described as the triad of physical and virtual siblings and their connections (Grieves and Vickers, 2017, p. 92; Grieves, 2019). The connection is the set of sensor and data transfer technologies that passively and actively read the physical twin and that feed into the digital twin.

To create digital twins, the literature usually distinguishes in Digital Twin Technology Development (DTTD) between several layers: data acquisition layer, transmission layer, digital modelling layer, data/model integration layer, and service layer (Lu et al., 2020, p. 5) (Figure 1). In the third layer of DTTD, digital twin modelling layer is where digital models can be created by using computer-aided design (CAD) software (Segovia and Garcia-Alfaro, 2022, p. 13) (Rhino, Revit, Solidworks, etc. (Lo, Chen, and Zhong, 2021, p. 8)) or other modelling tools (for existing structures it is possible with 3D scanning (Lo, Chen, and Zhong, 2021, p. 8)). When appropriately modelled, they can be used to simulate the behaviour of the physical twin under different scenarios (Grieves and Vickers, 2017, p. 96). Here, designers are aware of the parameters of the model data and sensor data (Lo, Chen, and Zhong, 2021, p. 8). Digital twin data can be collected

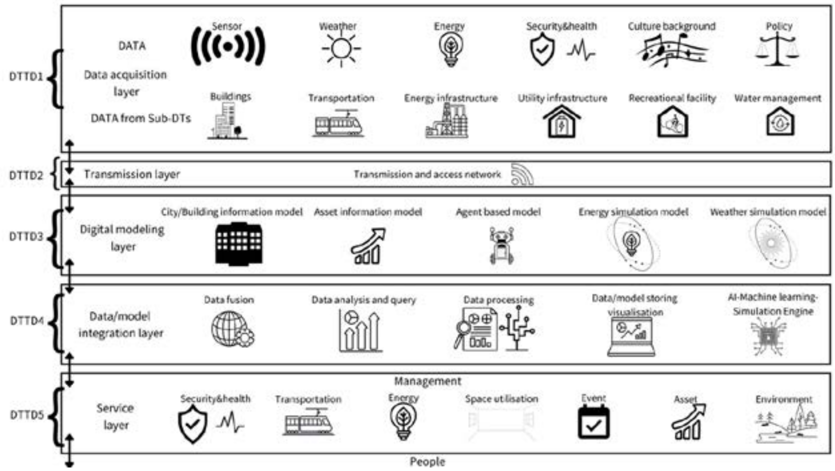

Figure 1: Digital twin technology development layers (DTTD) (adopted from Lu et al., 2020, pp. 5 by Emir Isik and Achten, 2022a, p. 49)

and recorded within sensor technology, so designers must carefully select sensors. Because this directly influences the scope of data that can be registered. At this point, 5G and wireless technologies also provide benefits such as no delay (Lo, Chen, and Zhong, 2021, p. 8).

Madni, Madni and Lucero (2019, pp. 3-4) emphasise that digital twins are different from CAD as follows: by reflecting the physical twin's status of the structure, performance, and task-specific character; by helping to determine the physical twin's maintenance history and schedule the maintenance; by helping to understand the physical twin's performance; by helping to understand the physical twin in operation; by supporting traceability between lifecycle stages; by making it easy to make predictions about future system performance; by combining data from the Internet of Things with data from the physical twin to identify necessary design improvements, and by reflecting the age of the physical twin by the data getting from the physical twin and digital model and simulations.

In our view, there are many benefits to using digital twins in the design process, including:

Digital twins can be used to identify and solve problems that can be detected when testing a physical twin equipped with sensors that collect real-time data and process historical data. This can help reduce the time and cost required to develop and test new products and systems, as it allows designers to identify and resolve issues early in the design process. It can enhance the accuracy of the design by allowing designers to simulate and analyse the performance of a system under various conditions. Thus, it can provide designers flexibility to quickly and easily test and compare design options. It can improve collaboration between design teams through the design process (Tao et al., 2018a).

While there are many benefits to using digital twins in the design process, there are also some challenges designers should be aware of. These challenges include:

Data collected from sensors or others need to be properly stored and managed for the management of data (Tao et al., 2018b). Digital twins may need to be integrated with other systems and software tools (Qi et al., 2021), which may require significant effort and resources. Digital twins can be complex and require specialised knowledge and skills to create and maintain. The initial cost of developing a digital twin can be significant, especially for more complex products or systems (Tao et al., 2018a, p. 3574; Madni, Madni and Lucero, 2019, p. 9).

There are a few key aspects that designers should consider when implementing digital twins in their work:

Designers should clearly define the scope of the digital twin (VanDerHorn and Mahadevan, 2021, p. 7) including the specific system being modelled and the specific design goals and requirements. Many different software tools and platforms are available for creating and managing digital twins. It is important to choose the right tools for the specific needs of the project. The accuracy of data collected from sensors and other sources is critical to the success of the digital twin. It is important to ensure that the sensors are properly calibrated and positioned, and that data is transmitted and stored appropriately. Digital twins can be complex and it is important to have a clear plan for creating and maintaining the digital twin to ensure it remains accurate and up to date. Digital twins can be accessed and shared by multiple team members, which can facilitate collaboration and communication throughout the design process. It is important to set clear roles and responsibilities for team members and to ensure that all team members have the skills and resources to contribute to the project (Tao et al., 2018a; Tao et al., 2018b).

3. HYBRID PROTOTYPES AND DIGITAL TWIN

Prototyping is at the centre of many design processes (Camburn et al., 2013; Jensen, Elverum and Steinert, 2017; Kent et al., 2021, p. 1). A prototype can be defined as the embodiment of a design for learning, analysis, refinement, and communication purposes (Camburn et al., 2017, pp. 3 & 4). Prototypes represent the ideas, concepts, and relations of physical and digital artefacts for the architects (Burry and Burry, 2016, p. 12; Emir Isik and Achten, 2022b, p. 56).

We can observe an increasing coupling of physical and digital models of prototypes, for testing and simulations and convergent solutions to improve understanding of the final design. Possible technological advances such as DT improve the connection between digital and physical environments. The combination of both environments provides more time, lower cost, and higher quality (Snider et al., 2022, p. 1767). Sharma et al. (2022, p. 1) highlight DT's state of the art that reduces the cost of prototyping, performs virtual testing, predicts the future behaviour of the prototype, monitors the real-time data of physical twins, and provides real-time analysis. From concept design to final design, physical prototypes (for discovery and communication of form, testing physical performance and behaviour, and validating digital model analysis) are utilised throughout the design process (Kent et al., 2021, p. 4). Digital prototypes can help create physically difficult complex shapes using the technology of some functions such as parametric design, simulation, Building Information Modelling (BIM), digital fabrication, etc. (Kim, 2019, pp. 4-10). As Wang (2002, p. 4) states, a digital prototype is a type of model or simulation of a physical when created and tested. There are several tools-processes where digital prototyping encompasses CAD modelling (parametric modelling, freeform surface modelling, point clouds, generative design), systems modelling (agent-based modelling), or simulations and analysis (Finite Element Analysis, Computational Fluid Dynamics) (Kent et al., 2021, pp. 5 & 6).

Hybrid prototypes thus extend the notion of the traditional prototype, which usually is a static and unconnected object to the digital model. Additionally, hybrid prototypes put more emphasis on real-time monitoring and simulation than is usual in the design process.

Hybrid prototypes supported by using DT technology are a combination of physical and digital models. Specifically, our focus is on the built environment, where hybrid prototypes can operate using a variety of sensors, actuators, and processors related to physical prototypes (Jones et al., 2019, p. 2558; Kim, 2019, p. 7; Delgado and Oyedele, 2021, p. 10) to simultaneously collect and react to data by applying DT technology. Design supported by efficient prototyping can be positively successful (Kent et al., 2021, p. 1). Physical and digital prototyping has helped to synchronise mixed reality (MR) technologies in the design process with design prototyping (Kent et al., 2021, p. 2).

4. FOETAL, CHILD, ADULT PHYSICAL AND DIGITAL TWIN

In the early stages of the design process, there is no real counterpart in the world on which to base a DT. Once the design has been initiated, the physical twin can be used to evaluate design performance with hybrid prototyping tools. In the design process, prototypes evolve as ideas evolve; foetal, child, and adult digital twins develop in much the same way. The foetal digital twin is at the beginning of the concept design and can be combined with several sensors in the form of a simulation or physical-scale model. The child digital twin can be a door or window model, a facade prototype, a shading system mock-up, or a wall prefabrication equipped with sensor technologies. The foetal and child twin can have a design influence on adult twins in both real and virtual environments (Emir Isik and Achten, 2022b, pp. 52 & 56) (Figure 2).

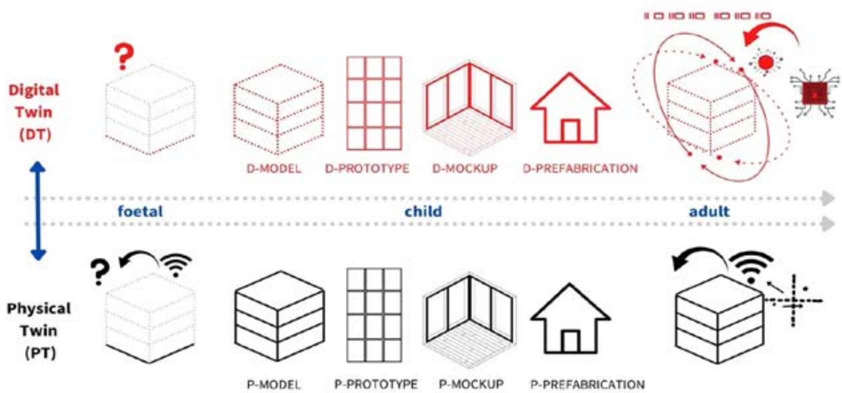

Figure 2: Prototyping with Digital Twin and Physical Twin through the design phases (Emir Isik and Achten, 2022b, p. 57).

According to Madni, Madni and Lucero (2019, p. 4) when these data are used to feed the digital twin (foetal, child, and adult), it is possible to read the story of the physical twin (foetal, child, and adult) of the design process (Emir Isik and Achten, 2022a, p. 48). The sensed data from the physical prototype will be used in a DT to actuate and monitor the current status, and the digital prototype will be used for the simulation, optimization, and prediction of future status (Madni, Madni and Lucero, 2019, p. 4; Boje et al., 2020, p. 10).

The notion of foetal, child, and adult digital twin gives us a useful framework to match developing physical and digital models that respond to the design phases in the architectural design process.

5. DIGITAL TWIN TECHNOLOGY AND IOT INTEGRATION

This section first examines the (5.1) Digital Twin in Design Process (DTDP): data acquisition by sensors, then (5.2) sensor network and design, then (5.3) design catalogue: a sensor network.

5.1. Digital Twin in Design Process (DTDP): Data Acquisition by Sensors

As seen in the Digital Twin Technology Development (DTTD), sensor network establishment is one of the first tasks that can be accomplished for a DT; the first layer is the data acquisition layer (Lu et al., 2020, p. 5). What data can be obtained is mostly about real-time data capture. These data are then processed. There is a central area for interconnecting sensor networks. In the DT ecosystem, these networks are in a data-sharing relationship with each other (Lehtola et al., 2022, p. 5). This layer is primarily achieved with the help of IoT tools and is mainly concerned with the retrieval of data by using several sensors in the DTDP framework in the first stage which mainly argues "what do designers want to achieve through DT". Thus, designers set the goal of the DT. This first stage as DTDP1 (=(P1) Function

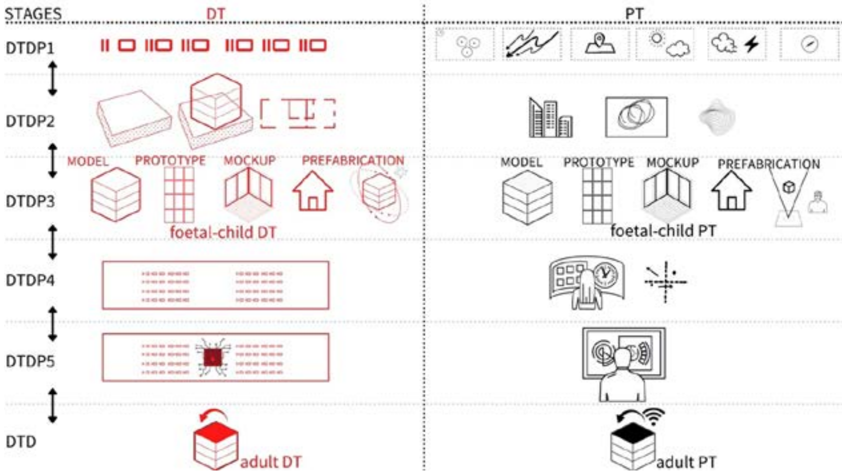

Figure 3: Digital twin in design process (DTDP) framework (adopted from Emir Isik and Achten, 2022a, p. 53)

+ (A1) Analysis ? (DTTD1) Data acquisition layer + (DTTD2) Transmission layer) can include some sub-questions such as "what DT should monitor?"; "what DT should track?"; or "what DT should register?". Thus, it contains the answers to the following: "what kind of data can I get?" or "what kind of data do I need?". Finally, some steps include the data set to be followed in DT (Emir Isik and Achten, 2022a, p. 51) (Figure 3).

BIM is the base of digital architectural modelling which contains the relevant information on the physicality (Eastman, 1999). BIM technology has become the focus of architectural design support with digital simulation of architecture in a digital environment (Eastman et al., 2011). According to Chang, Dzeng and Wu (2018, p. 2), BIM needs to be supported by plugins (Firefly, Revit API, etc) to cooperate simultaneously with the physical environment.

Ultimately, data combination will be achieved with the help of BIM and IoT in the third stage of DTDP. To guide the design process efficiently, it is important to decide where the sensors will be, because, after the final design and operation, things will be handed over to a facility manager or DT manager at the last stage of DTDP (Emir Isik and Achten, 2022a, pp. 51-52).

One of the case studies by Kensek (2014) has proven that Dynamo as a scripting language with a BIM model is effective in collecting data from Arduino environmental sensors (humidity, sunlight, and CO2). Arduino board (http://arduino.cc, single chip microcomputer, actualize the programs) can be used for attaching the sensors (motion, temperature, humidity, lighting levels, air quality) easily for transferring the simultaneous data to internet feed (Kensek, 2014, p. 3). Natephra and Motamedi (2019) point out that the integration of BIM-IoT has begun to create platforms to support processes in the AEC industry. They state that sensor data (Petrova et al., 2019) visualisation must be done meticulously, as it is useful to read and predict the sensor data. They used Arduino via sensors to simultaneously collect comfort parameters (eg. indoor air temperature, humidity, light intensity). They transfer the collected data to BIM and store the related data with visual programming. Thus, Augmented Reality (AR) is used to display real-time sensor data with developed virtual graphics. They mostly use Revit, Unreal Engine, and a few plugins for scripting. They first install IoT sensors for real-time data collection with comfort parameters. The Otaniemi3D platform is an example of BIM-IoT integration, a system for monitoring users' comfort and energy (Dave et al., 2018). Another example is operating cognitive buildings to monitor user behaviour and predict the performance of buildings (Pasini et al., 2016). Therefore, Chang, Dzeng and Wu (2018) examine BIM-IoT integration via automatic data transfer.

5.2. Sensor Network and Design

Grieves (2019) specifically looks at the relationship of the physical twin to IoT disclosure (with features such as sensing, comparing, reacting, and communicating). What we can sense using physical twins is driven by design criteria developed by hybrid prototypes at DT: identity, components, energy efficiency, temperature, humidity, lighting, magnetic waves, shape, materials, and aesthetics (Grieves, 2019; Kim, 2019, p. 2). While designing the physical environment thanks to our senses, the interaction of the users with the environment needs to be taken into account regarding the overall sensory comfort (Clements-Croome, 2004, p. 73). The building components are interconnected in systems called ecosystems, nowadays, which is eased with the pervasive sensor networks and IoT technology. It is started to be called as an uncritical manner responsive or interactive (Achten, 2019, pp. 3 & 7). The building system is intended to dynamically adapt to perform (optimization criterion such as lighting, acoustics, isolation), sustain (optimization energy and waste), serve (demanding such as air-conditioning, lighting, installation, communication), symbolise (representing common) and entertain (supporting the social according to function of space) (Achten, 2013, p. 480; Achten, 2014, p. 484). The sensor or actuators can be used for lighting, day-light control, sun control, renewable energy, and ventilation based on a knowledge of environmental data (Kensek, 2014, p. 2).

Achten (2015, p. 629) underlines that technologies such as IoT are powerful to unify and change architecture without professional evaluation of architects. Thus adds on, it is essential that architects are aware of these technological developments and their impact on architecture and the architectural profession. The purpose of IoT is to create a computer representation of the physical world that can be used by the digital world entities (Achten, 2015, p. 624). Interactive architectural works in transition with digital and physical, highlights technologies that sensor (reads the environment); controller (makes decisions for the system based on sensor system), actuator (enables or displays actions) and materials (acquires actions) eased the application of architecture (Achten, 2013, p. 478; Achten, 2019, p. 2). Gordon Pask observed that architects design systems rather than buildings, and therefore they must resort to cybernetics to design such buildings (Achten, 2019, p. 2). As an architect we should know how to implement these technologies from the beginning of the design process. Architecture team should not just look at the space and function, also they should care about the building personality (Achten, 2013, p. 479). To do that, digital twin technology may be used to achieve this approach, not just looking at the materials or performance, it can help to assume the buildings behaviour. Clements-Croome (2004, pp. 11-14) mentions in intelligent buildings sensor technology affects the design, construction and operation of the process. Thus, sensor application to the materials are eased by the help of the materials molecular scale. With embedded sensors, it is achievable sustainable solutions by providing the data for energy consumption.

The sensors applied to the hybrid prototype are vital to DT, whose task is to collect data from the physical twin and synchronise it with the digital twin for simulation and analysis by providing user input, environmental data, design information and fault logs. Data must be evaluated to be meaningful for the design. Therefore, data collected from sensors must be accurate in order to value DT. For concrete data, sensors must be carefully selected and placed carefully for the early design phase (Lo, Chen, and Zhong, 2021, pp. 8 & 11).

5.3. Design Catalogue: A Sensor Network

In this section, an architectural design catalogue includes sensors during hybrid prototyping to guide designers. This sensor network can be a guide for a building. For example, it can be in sentient buildings with a sensor-driven monitoring and control system with internal representation of the building (Mahdavi, 2004 given by Achten, 2014, p. 484).

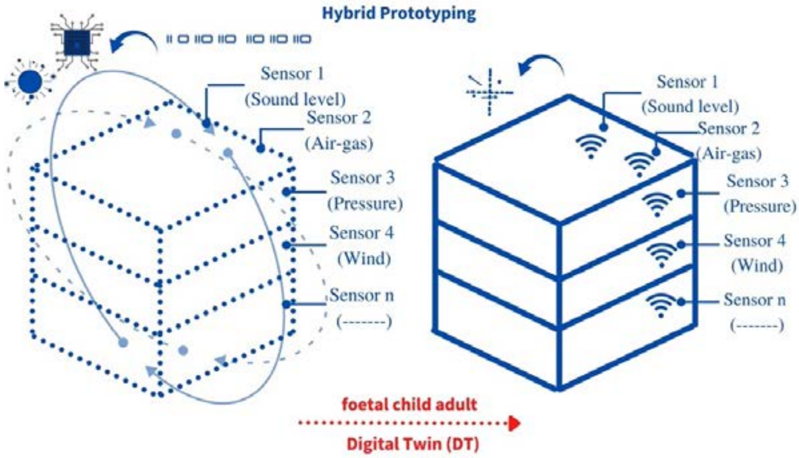

Figure 4: Hybrid prototyping and sensor network for foetal, child, and adult digital twins

A systematic list of important aspects of sensors for foetal, child, and adult digital twins is given in Table 1. The relevant data type and sensors, along with their definitions, are provided as follows: acoustic comfort *(sound level sensors)*; air quality *(air-gas sensors, pressure sensors, wind sensors)*; soil quality (*conductivity sensors, pH sensors);* spatial use *(occupancy sensors)*; structural *(acceleration sensors, displacement sensors, force sensors, gyroscopic sensors, strain sensors, vibration sensors)*; tactile comfort *(touch sensors)*; thermal comfort *(humidity sensors, temperature sensors)*; visual comfort *(color sensors, contact sensors, daylight sensors, passive infrared sensors, proximity sensors)*; water *(pH sensors, rain sensors, soil moisture sensors)* (Figure 4).

This system of sensors can affect the building behaviour of the future building (adult physical-digital twin). In a way that adapts simultaneously for performing, sustaining, and serving, it symbolises and entertains space (Achten, 2013, p. 480; Achten, 2014, p. 484).

Table 1: Sensor network for foetal, child, and adult digital twins

What kind of sensor	What kind of data	Description
Sound level	Acoustic comfort	to measure the intensity of sound, and this can be useful for monitoring noise levels or analysing the acoustics of a space
Air-Gas	Air quality	to measure the quality of air, and this can be useful for monitoring indoor air quality or collecting data on the performance of ventilation systems
Pressure	Air quality	to measure the pressure, which can be useful for analysing the performance of HVAC systems or monitoring the air pressure of a space
Wind	Air quality	to measure wind speed and direction around a building, which can be useful for analysing wind loads on a structure or predicting the performance of wind turbines
Conductivity	Soil quality	to measure the ability of the soil to conduct electricity; this can be useful for estimating the possibility of corrosion or monitoring the health of the landscaping
pH	Soil quality	to measure the acidity or alkalinity of the soil around a building; this can be useful for estimating the possibility of corrosion or monitoring the health of the landscaping
Occupancy	Spatial use	to detect the presence of people and can be useful for automating lighting and HVAC systems or collecting data on a building's usage

Table 1 Continued: Sensor network for foetal, child, and adult digital twins

What kind of sensor	What kind of data	Description
Acceleration	Structural	to measure the acceleration of a structure, which can be useful for analysing a structure's performance or predicting the probability of damage
Displacement	Structural	to measure the movement or displacement of a structure, which can be useful for analysing a structure's performance or predicting the probability of damage
Force	Structural	to measure the force applied to a structure, which can be useful for analysing a structure's performance or predicting the probability of damage
Gyroscopic	Structural	to measure the angular velocity or direction of a structure, which can be useful for analysing a structure's performance or predicting the probability of damage
Strain	Structural	to measure the deformation of a structure, which can be useful for analysing a structure's performance or predicting the probability of damage
Vibration	Structural	to measure the intensity and frequency of vibrations in a building or structure, which can be useful for analysing a structure's performance or predicting the probability of damage
Touch	Tactile comfort	to measure the detect and record of a physical touch
Humidity	Thermal comfort	to measure humidity, and this can be useful for controlling HVAC systems or monitoring the relative humidity of an area

Table 1 Continued: Sensor network for foetal, child, and adult digital twins

What kind of sensor	What kind of data	Description
Temperature	Thermal comfort	to measure the temperature, and this can be useful for controlling HVAC systems or monitoring the thermal comfort of a space
Color	Visual comfort	to measure the colour of the material surface
Contact	Visual comfort	to measure real-time status of items around the building and detect whether parts are open or closed
Daylight	Visual comfort	to measure the amount of natural light, and this can be useful for controlling lighting systems or optimising the use of natural light
Passive Infrared	Visual comfort	to measure the infrared light radiating from objects in its field of view
Proximity	Visual comfort	to recognize the proximity of the object and outputs the corresponding switch signal
pH	Water quality	to measure chemicals, ions, organic elements, suspended solids and pH levels in
Rain	Water quality	to measure precipitation on or around a building, which can be useful for activating rainwater collecting systems or predicting the probability of flooding
Soil moisture	Water quality	to measure the moisture content of the soil around a building, which can be useful for estimating the likelihood of erosion or monitoring the water needs of the landscaping

6. CONCLUSION

The use of digital twins in the design process, particularly in the development of hybrid prototypes involving sensors, has the potential to significantly increase the efficiency and accuracy of the design process. By allowing designers to simulate and analyse the performance of a product or system under various conditions and providing the ability to collect and analyse.

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SMART COAT: SHAPE UP OR SHIP OUT

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ABSTRACT

Our relationship with the physical world was transformed by digital tools; we see with digital cameras, listen to compressed digital files, use AI personal assistants and experience VR. We live in a world of smartphones, smart buildings, and smart cities. Reality has flattened, and screens have turned into spaces and spaces of everyday life. Therefore, the traditional architectural space has melted. Besides this, through the process of designing and making, the dialogue between man and material is directly related to the techniques and tools of that period. When it's the case, our new tools are '1' and '0's, and new composite materials should be in the game.

In the context of all these triggering factors, although digital processes represent a radical departure from normative practices still the role of an architect is not more than drafting instructions for buildings. The disconnected relations between architect and construction is the fundamental problem.

Through the dissemination of digital modeling tools during the past decades, the ubiquitous representation of the architectural product

is surface, façade, and shell, whereas the design and construction of the core or inside are still stereotypical and incompatible with the logic of the shell. Besides Digital Twin and BIM which works in traditional relationships of AEC, 'Smart Coat' targets to reveal an intertwined system of design and construction based on close interaction between designer and product and resilient circular conversion.

'Smart Coat' forms from inside to outside, from the smallest unit to the larger unit with human and object interaction, designing and making process which is intertwined in the action of artisan's hand. Because the smaller unit of architectural space can give us more freedom in design and can allow us new opportunities in terms of speed, multi-materiality, and reversibility. The project will advance examples inspired by nature, digital studies, and technological developments.

Keywords: Computational Design, Mereological Tectonics, Spatial Perception, Resilient Circular Conversion

1 INTRODUCTION

Throughout history, technological and cultural values of architecture have been embodied with materials and tools. Over the 20 years, digital technologies have cultivated a significant paradigm shift in architectural research and practice. The use of new digital technologies has transformed lives which has a deep cultural impact same as architecture.

Traditionally, three major factors influenced the form of what man has built.

- Space is what we need, such as shelter, a symbol of power, utility, beauty, etc.
- Tools are our ability to assemble and communicate with the idea, etc.

· Material is what is around us or to find ways of adopting and using it. (Neal Leach et al., ed., Digital Tectonics 2004).

In addition to Leach's three main subjects, the role of an architect or designer in the design and construction process should be added.

1.0.1 Space

New digital technologies have transformed our lives radically. We see with digital cameras, listen to compressed digital files, and use AI personal assistants, such as Siri and Google Assistant. People stare at their phones and laptop screens for hours every day. We live in a world of smartphones, smart buildings, and smart cities. Without software, airports are big waiting rooms, and supermarkets are huge warehouses until the cash register system runs again.(Kitchin Rob & Dodge Martin, 2011). Our society lives in front of the screens, waiting for the response of a WhatsApp blue ticks. Every cell phone screen is an architectural place, and nowadays, with the outbreak of Covid-19, our screens turned into public spaces and theatres every day. Thanks to technology, we are available 24 hours a day, 365 days a year. Private and public life is intertwined. We are a virtualization of humans where the physical bodies are transformed into zeros and ones (Fraile, 2019). Recently with the importance of design in the computer environment, the definition of architecture has begun to blur, and traditional architectural space has been melted because new space is 7- inch phone screens. New spatial perception has been flattened by the digital world. The list of the transformed relationship of the physical world by digital tools goes on and on. Our lives and physical environments have been changed radically, traditional architectural space is melted, the reality is flattened even further, and it is passing faster. The first question is, what and how should be the new generation architectural space?

1.1 Tools and Materials

Architecture product is the essence of its time and is a complex organism that synthesis of spaces, surfaces, structures, and materials. In the design process, the hierarchical relationships between traditional space and materials have been changed with tools and techniques. Through the process of designing and making, the dialogue between man and material is directly related to the techniques and tools of that period. Tools not only have a dynamic communication between design and construction but also provides new directions for creation and innovation. Tools are the media of mutual intervention between humans and subjects. Architects have come a long way and changed from the ruler and the right-angle applications to the present day. Simple design tools such as pens, compasses, and rulers have been replaced by computers in the last four decades.

The material defines the skin, structure, and volume of a building from interior to exterior. Building technologies and construction methods were improved but building materials used in architecture remain traditional and rigid for centuries (Konarzewska, 2017). Until now traditional dry materials such as concrete, metals, glass, plastic, wood, and bricks have been used to construct. Although concrete was found hundreds of years ago, still domes have been built for mosques.

1.2 The Role of An Architect

Throughout history, materials were broadened, and the construction techniques became more complicated, the master masons evolved to master builders or architects. Architects were not only the masters of spatial effects but also, they are involved in the construction of buildings, so being an architect also meant being a builder for centuries cause the design information was construction information. From Greek 'Tekton' to the 'Master Masons of the Middle Ages' were in charge of all aspects of buildings. They had a central and powerful position in the production of the buildings from mastery of the material (stone in most cases) and its means of production. However, the tradition of master builders could not survive in Renaissance's cultural, economic, and social shifts and the abstraction of the plan, section, and elevation became adequate information to build (Kolarevic, 2003). Leon Battista Alberti wrote that architecture was separated from construction with the intellectual training of architects and artists from master builders. Architects were originally craftsmen; however, these evolutions have resulted in architects' gradual loss of knowledge and skills in construction and removed the architect from being directly involved in the shaping of buildings on site.

In the mid-nineteenth century, drawings of the earlier period became contract documents, and this started to widen the gaps between architecture and construction. In addition to that, general contractors and professional engineers appeared. The relationships between architects and other parties in the building process became a contractually defined process.

This remains up to now as a highly rigid codified process and it is the biggest obstacle of today. In the late-nineteenth century, Howard Davis noted that as the system evolved further, the role of the general contractor grew and the architect's connection to the craftspeople lessened. Conceptually and legally the design was split from the construction process. Architects detached themselves fully from the act of building and they gave up the power they had before unintentionally (Kolarevic, 2003). It is debatable that drawings emerged in the building industry because of the separation of design and construction. However, the lasting legacy is tens of thousands of drawings are required for a medium size project (Kolarevic, 2003). The authority that architects had once was dissolving.

Nowadays although digital processes represent a radical departure from the normative practices that redefine the relationships between conception and production, still the role of an architect is not more than a drafting instruction of a building. So, the last question should ask what the role of an architect in the building process is and should investigate regaining the power of a 'master builder' as an architect with digital technologies.

In the context of these motivation questions, should we continue with conventional construction methods and structures with traditional materials, or should we aim to investigate new generation space with new tools for design, production, and construction process. Or should we use new composite materials will create fully controlled projects which are taking advantage of all the possibilities offered by technology from nanoscale through macro-scale? In order to be able to answer all these questions, it will guide us to review the studies on architectural space and production technologies until today.

2 BACKGROUND

Designs are descriptions of nonexistent things which are stored in mind. What is designing in architecture? According to Yoon (2005), 'Architecture is the art of space in the design act, ideas are organized, resources are managed, and results are predicted. Architecture product is the essence of its time and is a complex organism that synthesis of spaces, surfaces, structures, and materials. Architecture vision is organizing space and elements of that space and defining the relationships between the object and the subject (Carpo, 2013). Moreover, the architectural practice includes designing and making activities, these are complex non-linear operations(Menges et al., 2017).In the design process, the hierarchical relationships between traditional space and materials have been changed with tools and techniques. So digital tools and production methods have changed the way we think, the way we discuss, and the way we construct architecture. Therefore, the new perception of the architectural project under the digital technological perspective includes mathematical algorithms, digital biological systems, and advanced structural systems, which are trying to detach from their historical load. (Fraile, 2019). Computational design, physical computing, and digital fabrication are new paradigms of complex designs. Computers and digital tools allow designers to navigate and generate complexity in a way that technology has not achieved before and give opportunities to investigate more alternatives to the design (Fraile, 2019).

2.1 Space

The first industrial revolution changed the way how we produce, and how we transform the production process from handicraft to machinery. John Paxton's Crystal Palace (1851) embodied the technological spirit of the Industrial Age and heralded a future of steel and glass buildings. The innovations in materials such as iron, steel, concrete, and glass changed the boundaries of the buildings. The production chain was separated from crafts while it has been connected to pre-construction design. The glass facades allowed the architectural space to become transparent and thus provide an interactive contact and blur the boundaries of interior and exterior (Kolarevic, 2003). The facade system was separated from the structure of the building. The Maison Domino's flat slabs and columns have no relation to the structure which means each floor can have different configurations of walls, windows, and rooms (Hight, 2008). At the end of the sixties, "Fun Palace" was a cultural center which has an adaptable and changing construction. Since the 90s architectural thought had employed a new language which is called software to design, describe, predict, and evaluate (Rossi & Buratti, 2018)Gregg Lynn's Embryological House is an anti-ideal villa, and this project was a series of house variations that was designed by animation software and fabricated by CNC milling. Houses are infinitely mutating series; no two houses were the same. Beginning of the 20th century, the 'Time Theory' was shifted to the "Space Theory'.

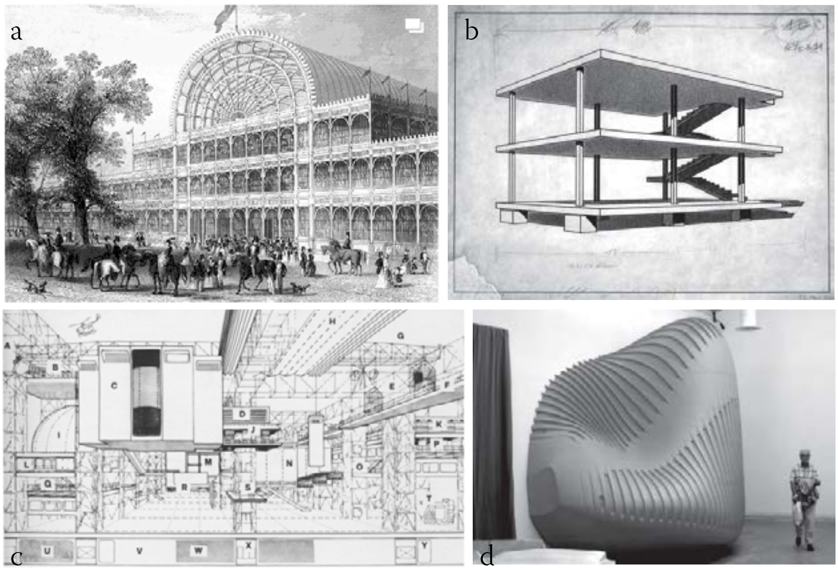

Figure 11 (a) Crystal Palace by Sir John Paxton, (1851). (b) Maison Domino Diagram by Le Corbusier, (1914). (c) Drawing of Fun Palace Interior, Cedric Price, (1961). (d) Embryological House by Greg Lynn, (1997-2001).

Hydra-Tesla Research Center (2011) is a passive responsive building that is a gigantic Faraday box. The noble design element is the structure as the cable phylum goes to the sky and spaces are stuck between the cable phylum. The augmented visualization project defines the procedure to communicate a complex digital model of the augmented Reality algorithm. The 3D interactive models reveal a new idea of space, nothing is physical but there is spatial perception. The Peony Pavilion offers a new form of theatre using the design of spatial interactive installation which assess the relationship between performance, space, and audience. (Yuan et al., 2019).

Figure 12 (a) Hydra-Tesla Research Center by Milos Vlastic, Vuk Djordjevic, Ana Lazovic, Milica Stankovic, (2011). (b) Application of AR to a digital model of the picture by Alberto Sdegno, (2018). (c) Peony Pavilion Body motion and augmented reality

Space and surface are not a rigid perception from the rigid boundary of Cristal Palace to the Peony pavilion's boundary, from the emptiness of Fun Palace to the Hydra-Tesla Research Center's fullness. Space and surface are produced by social relations and shaped by techniques and tools. Space is not a simple volume, and the surface is not a simple component that surrounds us. Space and surface are produced by social relations and shaped by techniques and tools. Space is not a simple volume; the surface is not a simple component that surrounds us.

2.2 Tools and Materials

The definition of craft often refers to custom work performed by hand. Tools are the media of mutual intervention between humans and subjects. Designing and making in the design process have intertwined in the action of the artisan's hands. The artisan can create objects without any preliminary sketches because making and thinking are part of the design act. Historically tools of the craft were extensions of the hands, and a good artisan has good hand, eye, and mind coordination (Klinger, n.d.). Unlike a painter or sculptor, the architect works on an intervening medium such as drawing; they do not have direct contact with the material and the outcome. Product designer has direct contact with his/her product. Whereas with digital tools, in a prefabrication project, every design decision must be checked against the manufacture and assembly process. (Sheil et al., 2020). This process allows architects to have direct interaction with the product. Digital fabrication technologies impact architecture, design methods, and production approaches (Rossi & Buratti, 2018).

Marvin Minsky predicted that in the 1960s; computers shaped our entire lives. Digital Revolution has been changing our world, which is not just about the shape; it is changed our approach to the design process. Gordon Pask noted the role of the designer is no longer as a controller of a design, but rather, the designer is now the designer of the apparatus that will design the product. (Johnson & Vermillion, 2018).

According to Sheil, the aim is to design a building traditionally, but in digital thinking, the aim is to design a system that can design the building. Wikihouse (2010) project is an open-source philosophy in architecture. An open-source downloadable construction set is available for everybody who can be able to involve in the design, fabrication, and construction of customized houses. This open-source architecture will give the opportunity to the people to participate in planning their cities, and building their houses, their public areas, and facilities (Naboni, 2015). 'Digital Grotesque' is 3D printed grotto with unlimited complexity. The structure is a fully enclosed room that is printed with sandstone and is articulated by millions of microscopic forms. Outside of the project is cubical volume while its interior features complex geometry that consists of millions of individual facets. So the final product is both ornament and a structure (Naboni, 2015).Cilllia is a hair-like structure, which can be found on animals and plants. Hair is a naturally responsive material that interfaces between a living organism and its environment by creating functions like sensing, locomotion, and sensing (Menges et al., 2017).

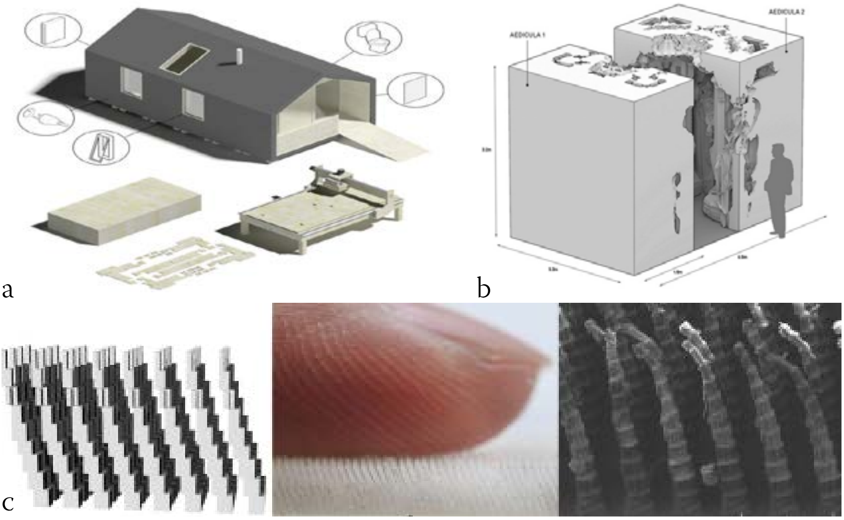

Figure 13 (a) Wikihouse, (2010). (b) Digital Grotesque by Michael Hansmeyer and Benjamin Dillenburger. (2013. (c) Computer visualization of printed hair; (b) close view of actually printed hair.

Digital light processing (DLP) 3D printer takes stacks of bitmap images from CAD models and directly projects on the liquid resin layer by layer. This 3D printing approach allows the design and fabricates of hair-like structures without making a 3D CAD model. The goal of this project is to bypass the modeling and slicing process of 3D printing, instead to generate directly machine-readable files that reconstruct hair-like structures (Menges et al., 2017).

Bioprinting is a commercial food processing that already uses extruders and other additive technologies to make chips and cookies. In FoodInk Restaurant in London, nine-course food is produced via live real-time 3D-printing right in front of their guests' eyes. Personalized 3D printed Sneakers '3D printed body architecture' is a new concept that could be defined by architects for clothing, and shoes. Mushtari research project is experimenting with 3D printed fluidic wearable design at the intersection of computational design, additive manufacturing, and synthetic biology (Patrick & Kolb, 2016).

Figure 14 Photo taken from Foodink.co website, (2021). (b) 3D printed sneakers, (2021). (c) Mushtari , (2014)

2.3 Craft, Digital Craft

According to Roth, as Nikolaus Pevsner's noted, painters and sculptors affect our senses by creating patterns, shapes, light, and color. But only architects shape the space in which we live and move (Roth, 2018). The relationship between thinking and making is originally held by the craftsmen's hands. Craft is work to meet people's material needs that are required experience, skill, and mastery based on learning and teaching. According to McCullough craft is the application of personal knowledge to give a form. It is a learning process based on handcraft (Sennett, 2008). Craftsmanship, in its simplest sense, started with the production of various tools that have become more functional but accumulated knowledge over time and study. According to Engels, labor begins with making tools. But today integration of the generative software opens a new type of designer-craftsperson. (Buratti, 2018). Architects become the 21st-century version of the medieval predecessors and can be able to gain the artisan title again through digital technologies. Digital craft can be a new-medieval discourse in the digital era.

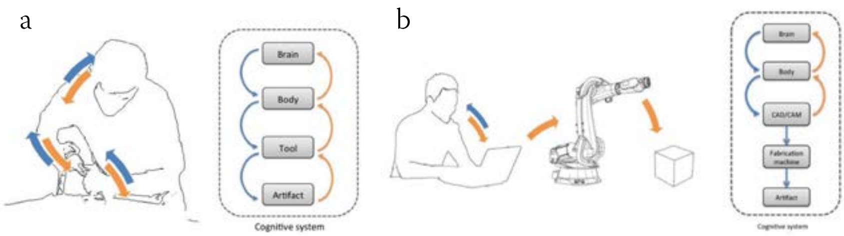

Figure 15 (a) Craftsman's Cognitive System (Ikeda et al., 2015). (b) Digital Maker Cognitive System (Ikeda et al., 2015)

The design and fabrication process involves complex cognitive activity that includes the human brain, human body, materials, and environment. The cognitive process involved in the process of design-making is started inside the brain of a human, but cognition is not limited to the mind. It is the coordination between internal attention and external structures (Ikeda et al., 2015). Craftwork involves bodily activity, either handheld tools such as chisels or more complex mechanical tools like milling machines ((Ikeda et al., 2015). In the last decades, human-controlled tools in traditional production systems have transitioned to computer-controlled digital production systems.

2.4 Shearing Model

The building is a dynamic structure that is constantly adapting to the user's needs and presents environmental conditions over a long-time frame. (Verberne, 2016). The building is not an assembly of inert construction materials and components; it is a living act embodying human memory, values, and actions. Buildings are conceived, designed, constructed, and used as entities. To understand the dynamic structure of a building, Brand Proposed a 'Shearling Layers' model. According to this model, a building is constructed from components with varying service lives, which requires changing or replacing at different rates shown in the figure (Verberne, 2016).

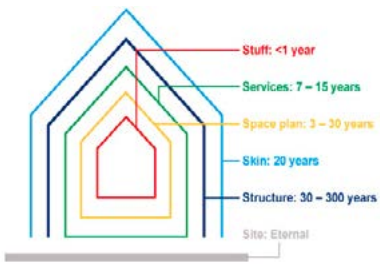

Figure 16 The Shearing Model, 'Six S' Diagram adapted from Brand (1994)

Fig. 2. The "Six 'S'" diagram, with each 'S' layer possessing different typical life spans. 'Stuff' denotes furniture, equipment and possessions. Adapted from Brand (1994).

From Renaissance until the first industrial revolution, architectural theories have produced the concept of a facade with different statements because the facade displayed the social status of the building owner to the city. According to the Violet-le-Duc, the facade reflects the interior arrangement of Antiquity and Medieval architecture, and for Semper and Loos, the surfaces allow the reading of the spaces. Then in the 19th century, the notion of a facade was converted to a surface notion. The building façade has a critical role as a mediator between nature and the indoor environment (Patterson et al., 2017). In this context, new research on digital technologies and production methods focuses mostly on the exterior/skin of buildings, whereas as in the Six S (Figure 1-6) diagram, the building consists of 6 layers. Furthermore, all these layers are formed around space, space is the center, and space is the fire.

3 'SMART COAT' STUDY

Through the dissemination of digital modeling tools during the past decades, the ubiquitous representation of the architectural product is surface, façade, and shell, whereas the design and construction of the core or inside are still stereotypical and incompatible with the logic of the shell. Besides Digital Twin and BIM which works in traditional relationships of AEC, 'Smart Coat' targets to reveal an intertwined system of design and construction based on close interaction between designer and product and resilient circular conversion.

'Smart Coat' forms from inside to outside, from the smallest unit to the larger unit with human and object interaction, designing and making process which is intertwined in the action of artisan's hand. Because the smaller unit of architectural space can give us more freedom in design and can allow us new opportunities in terms of speed, multi-materiality, and reversibility.

The project will be developed by two opposite production methods mereology/loading and carving/ unloading which are inspired by nature

3.1 Carving

From mass to cavity, from whole to the part that is inspired by the nature of carving is the first method to be experienced. Rock has no limited boundary to create a space. It is self-supporting with a complete infra-structure and does not need additional reinforcement.

According to the Cavern system of Cappadocia example inspired by nature, Underground cities represent a very special environment, from several points of view. Their size depends on the purpose, such as bedrooms, kitchens, bathrooms, stables for animals, water tanks...etc. Small-sized caverns were for the tombs, big sized caverns were for social purposes. (Nývlt et al., 2016). Based on a shearing model, structure and site were ignored, and space is carved when they need. Arzu Gönenç Sorguç mentioned that prestige skin is the visible and the oldest cave, which is the entrance, and the newest is the invisible and the deepest. These underground cities represent a very special environment, from several aspects.

Figure 17 General scheme for the underground city of Cappadocia, (Nývlt et al., 2016).

3.2 Mereology

The term mereology derives from the Greek word 'Meros', which means part. Mereology, as a term for a set of recursive assembly strategies integrated into the design aspects of the building parts, analyzes how social formations emerge, interact, evolve, and dissolve over time. At the intersection between digital thought and architecture, we offer an exploration of part-to-whole relations in architecture through research.

Mereology, as opposed to typology, is a methodological framework for designing an architectural object not through a reference to its content or form but through the resonance of its parts. (Köhler & Navasaityte, 2016) The geometrical design will be flexible in its variation, sizes, and several units and these compositional decisions allow new formal possibilities. Smaller units make many connections possible (Köhler & Navasaityte, 2016). Because the smaller unit of architectural space can give us more freedom in design and can allow us new opportunities in terms of speed, multi-materiality, and reversibility. Critically, the resolution is dissolution. This opens a foundational turn: the peer-to-peer paired decentralized decision-making (Koehler, 2019).

4 CONCLUSION

'Smart Coat' is not a shell design, it consists of combined 6 layers of the shearing diagram and is triggered by the new architectural space of Industry 5.0, Society 5.0, and Architecture 5.0. 'Smart Coat' defines and questions new architectural space to feel the 'power of the blow and the resistance' in the new design and construction process which emulates craftsman production. It is a system designed to store and circular the architect's design and architectural design information to change the position of an architect, as a hacker, moderator, decoder, or technician.

Etc. The broken traditional relationship between designer, producer, and consumer is restructured between humanity and machines, and the role of 'master builder' is regained.

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EXPLORING THE SPATIAL ORDER OF FUTURE DIGITAL ARCHITECTURE

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ABSTRACT

The conventional spatial order of architecture has been altered by the digital transposition of current digital architectural design and digital production. Digital architecture is combined and overlaid with the built environment and natural space, placing the spatial order in dynamic uncertainty. This creates a state in which both the old and new architectural spaces are entwined with order and disorder, and where both a single order and a number of diverse orders coexist. In order to accomplish the orderly development of future digital architectural spaces, this study aims to explore digital architecture from the perspective of spatial order, discussing the antidote/poison effect caused by the deep infiltration of digital technologies in architectural practice, and the cultural digital changes in digital architectures. It aids in perceiving the orderliness and aesthetic effect of spatial order, as well as striving to identify a new order of future digital architectural space that may be developed. Through the qualitative research methods of literature review and case study, this study collected data from literature analysis and specific cases, which relate to the creativity of exploring spatial order in digital architecture. The study selected four digital architecture cases, (W)rapper at Los Angeles by Eric Owen Moss, Beijing Daxing International Airport by Zaha Hadid, 3D Print Niaokan Bridge by Xu Weiguo and World Internet Conference Center by Yuan Feng (Philip. F. Yuan), hypothesising that the future special order of digital architectures will be a dynamic and balanced new spatial order. This new order includes the symbiosis of a human-machine and virtual-real hierarchy; the interactive co-existence between nature, humanity and technology; and the creative multi-immersive sharing of parametric information, built-environment resources and cultural artistic information. The evolution of spatial order of future digital architecture will be discussed in connection with the idea of the metaverse. This study's limitations are that it chose specific cases in a few countries, and thus didn't cover more of the world; and its lack of in-depth analysis of the formation of innovative technological culture, by only focussing on exploring the future direction of spatial order's development. The value of this work is its ability to inspire a broader examination of the new order of digital architectural space.

Keywords: Spatial superimposition, digital technology's antidote-&poison effect, the spatial order of digital architectures, alteration of spatial order

1. INTRODUCTION

The traditional spatial order has been changed by digital technology, altering the dynamic effects of inside architectural space and outside environmental space. The driving force behind the development of architecture has always been technological upheavals (Pitchnikova and Antyufeev, 2019). Digital technology is a driving factor in modifying the spatial order of architecture, as well as alternations in conventional architectural connections and shapes. The interesting point is that digital technology has a dual nature, having both an antidote effect and a poison effect As recorded in Gu Xuewen's (2018) interview with the French philosopher Bernard Stiegler, when asked about the influence of the technology on humanity, Stiegler says: "Technology is the antidote and the poison of humanity. Humans need to be wary of the heightened development of technology. Humans need to develop a new technical culture to deal with the new technological era." Meanwhile, digital technology had probably become a poison, producing a poisonous impact. For example, some of the new technological buildings are aimlessly seeking unique shapes, unusual functions and distinctive designs with the assistance of digital technologies. As a result, the interior functions of these buildings are in conflict with the rules, the structure of these buildings is in chaos, and their architectural forms and spatial order are in a state of 'disorder' (Kong and Yao, 2020). The newly digital architectures become part of the original environment and natural space, creating a superimposition of old and new space layout that changes the order of numerous spatial combinations.

1.1 Digital Architecture

The term "digital architecture" which first appeared in the middle of the 1990s, is the result of the impact of architectural construction becoming involved in digital technology. It is also a basic notion that has arisen as a consequence of the fast growth of digital technology and the global popularity and reach of AI. Digital architecture has been used to refer to buildings that feature digital technologies, with no delineation until now, but it is a product of the collision between digital technology and architecture, which applies to a spatial structure created using digital methods (Zhou and Yu, 2017). Digital architecture is a product of the profound integration of new-generation information technology with advanced manufacturing concepts, and includes the entire cycle and whole elements of the architectural construction industry (China Academy of Information and Communication Research, 2022). It is a crucial engine for enhancing construction levels and building quality, as well as for accelerating the transformation and upgrading of the architecture industry (China Academy of Information and Communication Research, 2022).

Digital architecture is the use of digital technology in the construction process and the whole cycle, the thus influences the building results, and is employed in the process of emphasising the digitisation of the building results. There are several definitions of digital architecture at this point, however in this research, the researcher believes that digital architecture is the process of architectural digitisation, and that "algorithmic architecture" same as "digital architecture".

Digital architecture has three main characteristics: digitised, interactive and intellectualisation. 1) "Digitised" refers to the process of digitising the whole process, including all aspects and participants, by deconstructing and modelling entities and physical actions and building digital models that are mapped into entities. It includes digital design, digital manufacturing, digital construction, digital operation and maintenance, and digital participants. 2) "Interactive" refers to the ubiquitous connecting real-time and online of HCPS (information physical system) based on "people, things, and objects" between the virtual building and the physical building, appearing in the form of a "digital twin" and generating a fusion mechanism of virtual-real mapping and real-time interaction. HCSPCS is an acronym for "high-capacity, high-performance computing system. 3) 'Intellectualisation' is a growing process that is data-driven and generates intelligent algorithms. In other words, the virtual building and the physical building can perceive, adapt, and predict based on big data and intelligent algorithms, and then rely on and optimise each other to become an “artificial intelligence” with comprehensive perception, analysis, and cognition, scientific decision-making, precise execution, and self-evolution, to realise the optimisation of resources in the process of closed-loop automatic data flow (Liu, 2017).

1.2 Space of Digital Architecture

In the early days, people separated architectural areas from natural environments with certain material constructions (Peng, 2008). The function of architecture is to form a space; it also serves to enclose a space, and social activity is contained inside this space. The creation of architectural space is the result of human activities in the realm of social production. It has committed to the theory presented in *The Production of Space*: ‘(social) space is a product (of society)’ (Lefebvre, 2021), and the combination of architectural space creates the fundamental shape of urban space. The city is a location that has been formed and constructed by social activities during a particular historical time (Lefebvre, 2021). Iterations of urban spatial patterns are always evolving in response to the shifting phases of human history, and the changes in spatial forms will trigger a change in the spatial order of the city. The advent of digital architecture as a form has resulted in the merging of digital technology with architecture, which has produced digital structures in the space. These digital architectures not only speed up the automated processing of building information, but they also enable architects to directly drive and manage the deployment of both natural resources and spatial information in reality via intelligence technology. The space of digital architecture mentioned in this study relates to architectural spaces that have digital architectural characteristics.

1.3 Spatial Order

Spatial order is the state that spatial patterns present at a specific time (Meng et al., 2019). Spatial order characteristics exist at multiple spatial scales, are hierarchical in nature, present spatial heterogeneity and spatial complexity with changes in spatial scale; meanwhile, spatial order exhibits distinct levels of non-uniformity and complexity at different spatial scales (Li and Reynolds, 1995). Order is the concept concealed behind things; it incorporates the aesthetics in space and surroundings via implicit methods and organises the shape of space with various representations (Zhang, 2018), such as architectural symmetry, stratification, spacing, and density. Lefebvre (2021) argues that "space is a social form; the space of order is hidden in the order of space ...... Space is neither 'subject' nor 'object', but a social reality." Thus, it is a collection of relations and forms (Lefebvre, 2021). The house or building started out as a way to protect people from risk; it creates a relationship between humans and their built environment, which forms distinct periods of relatively stable order. As technology advances, it alters the structure of physical space, ushering in a new spatial-technological order with cultural transformations.

2. LITERATURE REVIEW

Through variances in size, shape, and layout, architectural spaces produce order for their internal channels and nodes, and the organising principles of diverse orders directly lead to vastly varied forms of spatial arrangement (Hu, 2017). Digital architecture allows the integration of design and construction with the use of intelligence and digital tools, resulting in the creation of creative digital architectural spaces that defy the conventional principles of architectural organisation and spatial order while simultaneously developing a new order. This is accomplished via the process of generating digital architectural spaces. This research explores the spatial order of digital architecture and illustrates that the advent of digitalisation will usher in a new architectural period that is rich with significance. "Digital architecture" refers to the digital technical creation of architectural space that exists now, as well as Lefebvre's (2021) criticism of technological utopia and the quiet violence of architectural ideology, where technological utopia could produce the risk of technological reliance. It is the violent silence that destroys the original space order. Only by constraining danger and chaos can people construct a spatial order, in which nature, spirit, and society are united, symbiotic, and harmoniously intertwined. As Peng (2008) claims, the spatial trinity of "functional, aesthetic, and structural" which refers to organic and cohesive architectural space, will be reinterpreted and improved by virtual reality, augmented reality, mixed reality (MR), and extended reality (XR). In the last four years (2019 - 2022), architects and urban designers have explored multiple aspects in the theory and practice of digital architecture and architectural space, are which shown below:

2.1. Collaborative design methods

The design methods of digital architecture should backtrack to a structured technical strategy with consideration of the discipline's origins (Li et al., 2019). Designers employ digital and computational techniques to construct a "scalable algorithmic model of smart architecture " in the digital architecture's design process, which established a cognition between architecture design and AI. The algorithmic model introduced the new thinking and a valuable cycle with upgrades, which surpasses the logical limitation of the human mindset, in the space of probability for shaping the future of architecture (Li et al., 2019). Xu (2020a) highlights four technologies impacting architectural design from virtual to reality. The first is Virtual Reality(VR) and Augmented Reality(AR), which make the building of complicated forms easier; the second is artificial intelligence, whereby design tools of artificial intelligence may replace architects; the third is interactive technology, which pursues the genie loci by creating the interaction in architecture, people, and the environment, while giving people a personalised sense of belonging; the last is 3D Printing, which supports the constructed evolution of buildings, such as creating curved surfaces of architectures.

2.2. Intelligent construction evolution

The designer team led by Xu Weiguo made significant advancements in the application of smart manufacturing and 3D Printing materials into architectural practice (Xu, 2020a). These advancements included the creation of a 3D concrete printing-based housing system as well as a robotic arm mobile platform that is suited for architectural printing and is used in building construction (Xu, 2022). Yuan Feng's designer team explored the paradigm update of human-machine hybrid architectural creation and twin co-creation (Yuan et al., 2019), by defining a new subject under human-machine cooperation, suggesting a new mentality of intelligent enhanced design and evolution, and reconstructing the sense of humanism in the post-humanist age, wherehuman-machine co-creation is unavoidable (Yuan et al., 2022).

2.3. Digital transposition

Digitisation has changed the way residents and stakeholders live, work, cooperate, and communicate. Scholars have done useful research on how digital technology affects urban space and how people's lives and work change because of it. The related ideas and concepts of digital transposition are extracted from their results as follows: Digitalisation refers to a socio-technical method of adopting digitising techniques to improve social and institutional contexts (Seth et al., 2020). Ansong and Boateng (2019, cited in Jnr et al., 2021) define digital transposition as "the creative use of digital technologies (social, mobile, analytics, IoT, platforms, and ecosystems)" to tackle long-standing issues. As Kaplan and Haenlein (2019, cited in Jnr et al., 2021) claimed, digital transformation has the potential to result in disruptive innovation, the development of value networks, and new markets. The objective of digital transformation is to induce major change by combining information, computer, and communication technologies (Vial, 2019). According to a recent interdisciplinary assessment, there are three distinct phases of digital transformation: digitisation, digitalisation, and digital transformation (Verhoef et al., 2019).

2.4. Theoretical practice

Wei Likai's team discusses the positive significance of artificial intelligence intervention for architectural digital history from a future perspective (Wei, 2020). Based on the popular understanding of "digital being" of society, Zhang (2022) claims that the combination of the virtual and reality becomes prevalent in architectural design and research in the digital age. He provides an emotional orientation for discussing in depth the origin of digital architecture theory. Xu (2022) claims that architecture as a spatial carrier of robots would face the potential need for intelligent innovation and upgrading. By sequentially exploring the logic of incorporating perception, behaviour, and social capabilities in future architecture, Liu (2022) mentioned a new architectural design theory that is proposed to be highly integrative of robot- and human-living environments. Huang Weixin argues that diverse creative free-form building approaches have merged morphology, geometry, structure, and manufacturing as an extension of architects' design thinking and a wide cognitive framework during the last two decades.

Basic on the current literature reviews, there are very few results directly focussing on the "spatial order of digital architecture", but some that are partly related with digital architecture or spatial order. The four aspects summarised above could not be separated; there is crossover and permeation between the different aspects, with no clear boundaries in the mixture. In conjunction with the book *The Production of Space* and *The Theory of Architectural Space Combination*, the broad digitalisation of architectural space generates a multi-dimensional mixing of theories, practices, time, space, society, culture, and art. Modern architects need to build a poetic type of spatial structure for human habitation using digital technologies. Constructs as organisms are constantly impacted by the technical and cultural environments in which they are found as well as by the physical sensations and existential meanings of those who create and live in them. As a result, they are compelled to be in constant, dynamic change (Yan and Yuan, 2020). The traditional architecture order has been changed, and this study will explore the new order with its numerous aspects, and will look for a new order with technoculture in digital architectural space.

3. RESEARCH METHODS

This research adopts a qualitative methodology by using a case study approach to collect data from previous literatures. An effort is made to acquire knowledge of digital architectural and spatial order by extracting ideas from relevant literatures from 2017 to 2022. To address the integration of digital architecture practice and frictions in the spatial order, data was collected using case studies from specific cases. The terms and knowledge from the literature was coded with categories, then cross checked within the findings from the case analysis.

When searching the keywords of "spatial order of architecture" on the CNKI database for Chinese literatures, and the OneSearch database for English literatures, there are only 11 academic papers that are closely related to the topic, which shows that relevant research is lacking in quality and quantity. The following terms are associated with the spatial order of architectures: orderliness, regularity, organisation, unity, completeness, plasticity, diversity, continuity, hierarchy, adaptability, polysemy, difference, commonality, coexistence, morphology, topology, integration, transparency, orderly organisation, cultural arrangement. When searching the keywords "digital architecture", there are 204 papers, and when searching the keywords "spatial order", there are 244 papers, as show in Table 1 (Made by author).

Table 1 Related Key Words in Papers from 2017 to 2022

	2017	2018	2019	2020	2021	2022
Digital Architecture	30	43	49	37	43	42
Spatial Order	23	27	48	46	26	34

As the table shows, the number of papers peaked at 49 for the key words "digital architecture" in 2019, and 48 for the key words "spatial order" in the same year. This raises some interesting questions. The influence of the pandemic that started on 2019 and other unknown factors may have sidetracked the interest of the researchers involved. From the analysis of the literature on "spatial order in architecture", the author devised a research strategy of "digital architecture + spatial order", correlating digital architecture with spatial order, and exploring the spatial order of digital architecture. Searching for "spatial order of digital architecture" yielded 0 articles from 2000 to the present, which means that "spatial order in digital architecture" is a research topic with a degree of originality. Based on the objective of this research, the author chose four prominent digital architecture works in the worldwide context, to do case studies and investigate the changes in the spatial order of digital architecture.

4. CASE STUDIES

(W)rapper of Eric Owen Moss (Figure 1) is a tower in downtown Los Angeles that has no columns and no beams, which is full of clashes of forms and elevations that appear to be colliding, breaking, deforming, superimposing, bending, splitting, melting and exploding, as if out of control. All these architectural features cannot be relegated to any one methodology of design. Crossing the building's four elevations are ribbons of curved steel tubing. The only producers who can create these corners are in Shenzhen,

Figure 1 Photo of (W)rapper of Eric Owen Moss, 2019. Available at: https://www.archdaily.cn/cn/tag/eric-owen-moss [Accessed 12 Dec 2022]

China, and in Munich, Germany, where they combine many plates to create a solid with the required strength. China manufactures the ribbons, which are the most intricate steel components, for locations as far away as LA and Munich. In this case, utilising digital communication and information transmission across different cultural and national boundaries, the engineering and manufacturing were made feasible utilising by a common digital language for sketching, detailing, and production. This is made possible by shared technologies, which also provide the architects with access to technological assets internationally.

Digital manufacturing makes it possible to quickly produce and research a variety of solutions. As Moss (2019) mentioned: "In the past, the process would have been slowed down by activities such as drawing or building a model in the traditional manner. The project's design concept and conceptual approach are still derived from my hand drawings. However, the computer rapidly takes over and becomes a fantastic editing tool." (Xie, 2019). Eric Owen Moss's architectural work replaces the traditional way of making buildings by using the convenience and speed of digital technology. This makes it possible to build buildings that are global, shared, and built at the same time. The multicultural sharing of information, the worldwide sharing of construction materials and fabrication processes, and the tendency to utilise computers and digital tools to assist architects' designs are illustrations of the "antidote effects" of digital technologies. It can be seen from this case, that while digital intelligent design and construction alters the norms of traditional architectures, it does not totally replace the architect's job, but stay at the assistant level.

Beijing Daxing International Airport by Zaha Hadid (Figures 2&3) is known for its innovative use of unconventional construction techniques and new materials. Parametric design is the characteristic of the digital spatial representation of this case, which breaks with the style of appearance of traditional buildings appearance style. It also created a

Figure 2 Photo of Beijing Daxing International Airport, 2019. Available at: https://www.zcool.com.cn/work/ZNTMwMjkxMzI=.html [Accessed 31 Dec 2022]

Figure 3 Interior Photo of Beijing Daxing International Airport, 2019. Available at https://www.zcool.com.cn/work/ZNTMwMjkxMzI=.html [Accessed 31 Dec 2022]

new perspective that provides unlimited possibilities for further architectural development. Through parametric design, this airport project in Beijing is a conjugated and harmonised leaf-like structure, with the singularity of the structure at its centre. It combines traditional culture with modern design, the inspiration was a variant of the ancient Chinese phoenix, an auspicious symbol with a particular aesthetic identity that produces a regional aesthetic spatial order. Through layered interlacing, spatial curling, and increasingly intricate features, Zaha's building creates more agitated but organised motions with a pulsating perceptual power (Zhu Eilang, 2021). At the same time, her ideas disrupt the conventional forms of architecture by blurring the lines between roof and facade to give the building a fluid, modern, integrated, sculptural aspect. As digital technology pervades the realm of architecture, architects can play more freely with the rules of order, introducing chaotic methods such as tilting and crossing, dislocation and distortion into building design and construction, resulting in subversive, paradoxical, and uncomfortable constructions. This unorthodox ordered building hides a dynamic order under its rebellious exterior, exhibiting the beauty of a specific order. For example, architectural design with digital technology generates complex, multidimensional, and other dynamic shapes that constitute a new component of architecture and may establish a new aesthetic order. Spatial order affects and governs architecture's structure, organisation and way of being, and is the principle and logic of its creation. The beauty of architecture exists in order, and the aesthetic in digital architecture subverts the aesthetic order of traditional architecture, which implies the construction of a new aesthetic order in the space.

Figure 4 Photo of the 3D Niaokan Bridge, 2019. Available at https://www.rd.tsinghua.edu.cn/info/1054/1492.htm [Accessed 31 Dec 2022]

Figure 5 The Bao An Brand at Bao An Park (Using 3D Print technology to print the statues and words in the park, designed by Xu Weiguo's team, 2021. Available at https://www.archiposition.com/items/fe6b67f5b8 [Accessed 31 Dec 2022]

The 3D Print Niaokan Bridge (Figure 4) by Xu Weiguo earned the "Technology Use Award" at the ROB&ARCH (International Robotic Construction Conference) in 2018. It constructed the world's biggest concrete 3D printed pedestrian bridge in Baoshan, Shanghai, using its self-developed robot arm 3D printing concrete technology, which saves material, labour, time, and money in the building process (Tsinghua News, 2022). Figure 5 is the photo of the world's largest attempt to build a 3D printed concrete green park in Baoan District, Shenzhen.

As an intelligent construction technology, 3D Print permits not only the production of conventional building shapes, but also a range of rich organic architectural forms, allowing tradition and modernity to coexist. 3D concrete printing building technologies and systems are not simply a tool for production, but a new method of production that will result in the formation of a new social organisation. Xu (2020) asserts, on the basis of the intelligent integration of digital building design and construction, that "AI design tools may replace architects". This opinion contradicts Eric Owen Moss's idea that "the intelligent technology is an excellent tool for designers". As AI grows and penetrates deeply into the area of architecture, the future of digital architecture may alter the architect's identity, altering what architecture means to people and the human-machine synergy. Eric Owen Moss believes that people may utilise digital tools to produce architecture, but that these techniques do not guarantee the traditional meaning of architecture. The meaning of architecture comes from other things, such as culture and the way designers think about things (Xu, 2012).

The *World International Conference Center* by Yuan Feng's team (Figure 6 & 7) located in Wuzhen, won the top prize at the 2022 American Institute of Architects (AIA) International Design Awards for the Wuzhen Internet Light Expo Centre (Tongji News, 2022). Wuzhen is a historic town with cultural features in the Jiangnan area of China, and the development of a mega-expo centre of tens of thousands of square metres presented a formidable task (Figure 6), balancing the harmony between the scale of the traditional and modern buildings with the need to establish a new architectural order of the times. The design of the new venue for this case takes into account the continuation of spatial and functional integration with the current venues, as well as the future orderliness of

Figure 6 Photo of the World International Conference Center, 2021. Available at http://www.archcollege.com/archcollege/2021/11/50161.html [Accessed 31 Dec 2022]

Figure 7 Photo of the World International Conference Center, 2021. Available at http://www.archcollege.com/archcollege/2021/11/50161.html [Accessed 31 Dec 2022]

the overall built environment, with the interaction between tradition and modernity, technology and culture serving as the focal point of the overlaid spatial order of the site.

In order to conceptualise and build the centre in Wuzhen, the "traditional characteristic" and the "Zeitgeist" served as the starting point. The fusion of Zeitgeist and the culture of construction is the key point of creation (CMGJ, 2019), and the completion of the project entails the construction logic and formal logic of the new productivity of the creative process, as well as the cultural reconstruction of the digital humanities period. This case in Wuzhen is not only a new architectural space, but also a constructive experiment in the context of post-humanistic philosophical thinking (Yuan, Zhang and Ma, 2020). It is a mapping of technology and culture, a reconfiguration of the architect's identity, a revolution of the architectural business, and a paradigm shift in architectural discourse. The interweaving of traditional and contemporary architectural spaces in Wuzhen provides a complex variety order, where regional, traditional, and modern architectural characteristics are naturally merged, and where single and multiple orders tend to be organically harmonised. The combination of the traditional community culture of the historical town and the Zeitgeist in the digital architectural space creates a new techno-culture, heralding the techno-cultural transformation of the spatial order.

Internet technology, one of the technical cornerstones of digital architecture, has been repeatedly updated to the third generation and is regarded as a metaverse (Cheng, 2022). The combination of the metaverse and the encompassing Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Extended Reality (XR) with architecture and civil engineering (Wang et al., 2022), upgrades the technological applications of digital architecture. Multiple environmental data sets from the natural and social spheres are parametrised into computer tools, computationally produced, and then 3D printed into an integrated algorithmic architecture. These various technologies are driven and constrained by computational programming, which has an algorithmic order. The spatial superimposition of the algorithmic architecture itself, add to the superimposition of older places, results in the production of an intricate spatial order that contains both old order and new order simultaneously. Order requires complexity for its manifestation, and complexity requires order for its comprehension (Shi et al., 2010). In an effort to understand the future spatial order of digital architecture, the interpretation of these four cases investigates the cohabitation of the complexity of 'order/disorder' and the organic unity of 'single/multiple order' in space.

5. CONCLUSION

If “poetic space with order” is the architect’s goal for architectural design and construction, then the development of a sustainable place that fits into the natural order may be the direction for the production of a digital architectural spatial order. Natural and social environmental data are input into the design parameters, resulting in an algorithmic architecture that most closely resembles the natural and social spatial orders. The traditional rules of the spatial order of architecture are broken and subverted by digital architecture. However, the new digital architecture is placed in the built environment and natural ecosystem, where spatial superimpositions penetrate, rub, restrict, and converse with one other towards integration, reflecting order’s regularity. The construction of a new spatial order for digital architecture necessitates time to settle and identify with the process.

Spatial order can be discovered in digital architectures through the above literature and case studies: digital architecture both breaks and inherits the old architectural spatial order; the digital architecture has a binding and aesthetic in the order; it changes the relationship between digital technology and human, free up labour for a while, makes building in the highly efficient way, and this order is controlled and bound by human digital symbiotic order; multiple intelligent manufacturing technologies establish a combined order as digital technology penetrates deeply into the area of architecture, such as technological theory and humanistic theory, tradition order and modernity order; it uses computer technologies and the IoT to communicate parameters, sharing resources, to establish an sharing order. Meta-universe space will also develop the embryonic digital architectural spatial order features of symbiosis, communion, sharing, and the blending of reality and imagination. “Symbiosis” will demonstrate complex hierarchies, logical levels of algorithms, and hierarchies of human consciousness and social classes; "combined" will demonstrate cross-border, bionic, simulation, unrestricted interaction with reality and reality conversion; and "sharing" will demonstrate the sharing of a fully perceptual immersive experience, the sharing of immersive space. The result of the virtual evolution of the metaverse space can be projected onto the real space, and the symbiosis, commensality, and sharing of virtual and real space form a new technological culture, laying the groundwork for the future digital architectural space to establish a new order of dynamic equilibrium and foster its innovative development.

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A SCAN-TO-BIM METHODOLOGY FOR DIGITAL RECONSTRUCTION OF TIMBER STRUCTURES

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ABSTRACT

Nowadays, there is a great need for the maintenance, recycling, and reuse of construction materials from existing buildings. This could contribute towards the reduction of Greenhouse Gas (GHG) emissions, which are produced through the manufacturing of new building elements, and the construction of buildings. Due to this, new digital frameworks need to be developed for automating the process of identifying structures and materials in order to store their data for further processing and enable architects and civil engineers to decide which of these could be reused and maintained efficiently. One category of such structures that require special attention is the timber roof frames in existing buildings, which may need digital recording and documentation in order to be preserved or reused. In the literature, few works are observed in this direction, which include the digital reconstruction of historic timber roof structures as simplified geometries, the lifecycle analysis of reconstructed timber beams in BIM (Building Information Modeling) environment and the analysis of cracks in timber beams in order to be preserved. Limitations as regard the accuracy, the level-of-detail and the required attributes of final BIM models can be observed, especially in cases where digital information intents to be used for the conservation and reuse of heritage timber structures. In order to tackle current challenges in this direction, a Scan-to-BIM methodology is suggested that allows automatic creation of timber roof frames through an algorithmic procedure that integrates parametric and BIM environments, by following a series of steps that among others include the scanning, the segmentation of point clouds, the detection of the boundary points, and finally the automatic creation of complex BIM geometry with an improved deviation. Results are accompanied by material attributes aiming at lifecycle, environmental and cost analysis. Through this paper, a heritage building with a non-regular geometry is chosen for the digital reconstruction of its timber roof. Then, the application of the specific Scan-to-BIM methodology is exemplified, and finally, the accuracy deviation results as well as the required BIM attributes of their timber building elements is discussed.

Keywords: Timber roof construction; Preservation; Reuse; Terrestrial Laser Scanning; Parametric modeling; BIM.

1. INTRODUCTION

1.1. The need for the maintenance, recycling, and reuse of existing building materials

Currently, there is a necessity for the maintenance, recycling, and reuse of construction materials from existing buildings. This could decrease GHG emissions, which at the moment are numbered at 5 to 12% of the overall GHG emissions globally and are generated through the extraction of materials, the manufacturing of new building elements, and the construction and refurbishment of buildings (European Commission, 2020).

New digital frameworks need to be established for automating the method of specifying structures and materials with a view to store their data for further computation and to enable architects and civil engineers to determine which of these could be reused and maintained efficiently. Silva et al. (2022) suggested a Structural Inspection and Diagnosis (SID) methodology for the refurbishment of seven traditional buildings found in Porto city, Portugal. This method allows architects to maintain a range of structural components such as timber and stone walls that meet safety requirements and regulations. The application of the SID method along with the proposed refurbishment design can considerably reduce demolition waste and eliminate impacts to the environment. Moreover, Kim and Kim (2023) proposed both a graph-based and a design support tool for Building Information Modeling (BIM) that lets the designer to calculate CO2 emissions and the corresponding cost from a Design for Deconstruction (DfD) approach. Particularly, the user of this tool can create a variety of design alternatives in order to optimize the best possible DfD solution from the reuse of steel or timber structural components. Gordon et al. (2023) used a Scan-to-BIM method for an existing steel structure within a warehouse site in the process of demolition. The case study emphasizes on the creation of BIM models from point cloud data for demolition sites in order to manage a building deconstruction method and obtain benefit from the restored materials.

1.2. Scan-to-BIM examples

BIM technology could be used in order to process the attributes of existing building elements. Specifically, BIM refers to the action of designing, constructing, and operating a building or infrastructure project through the production of precise data and geometry generated by software processes (BSI PAS 1192-2, 2013). Furthermore, BIM relates to a socio-technical system and not a specific form of software. This system contributes to the creation of a project in regard to social, individual, physical, and informational requirements that demand a human-computer interplay (Sacks et al., 2018). However, the standard parametric objects created from current BIM software are not adjustable to the abnormalities found in the morphology of building components such as walls and columns especially in heritage buildings. In addition, the geometrical alterations that happen over the years could not be indicated. As a result, important work needs to be done for creating the geometric uniqueness of existing structures. To accomplish this, remote sensing technologies such as 3D Laser Scanning and Photogrammetry can be used to create the geometry of building assets and import them into BIM. This method in current literature is called Scan-to-BIM (Andriasyan et al., 2020). Specifically, Scan-to-BIM is used for a variety of research approaches. In particular, Banfi and Previtali (2021) developed an automatic workflow for creating BIM objects and Computer Aided Design (CAD) textured mesh geometry from point clouds derived from aerial and terrestrial photogrammetry and synchronize this data with an Extended Reality (XR) platform. Andriasyan et al., (2020) have also applied Scan-to-BIM methodology for automatically creating mesh geometry from point clouds captured through Terrestrial Laser Scanning (TLS) and specifying semantic data within a BIM software. Brumana et al., (2020) created a framework for the automatic generation of Non-Uniform Rational B-spline (NURBS) geometry and BIM objects from point clouds obtained from Photogrammetry and TLS. This method provided a Heritage Building Information Modeling (HBIM) model for facilities management (FM), environmental study and structural analysis. Scan-to-BIM has also been used for existing steel structures. Yang, Cheng and Wang (2020) achieved a semi-automatic workflow for creating as-built BIM parametric components from point clouds of steel structures processed through numerical analysis, visual programming, and BIM software.

1.3. Scan-to-BIM for timber roof constructions

As it can be seen from current literature, Scan-to-BIM methodologies have been used for a variety of building cases. One category of such structures that require special attention is the timber roof frames in existing buildings, which may need digital recording and documentation in order to be preserved or reused. Mol et al., (2020) used TLS for geometrical survey and electronically controlled drill resistance equipment for analyzing the structure of the timber roof of the Guimarães Castle and the Knights Room of the Christ Convent in Tomar, Portugal. This data was processed using point cloud and BIM software for the creation of a model that contains the building attributes of the existing timber beams and allows further lifecycle analysis for its maintenance. Pöchtrager et al., (2020) automatically segmented the point cloud and 3D reconstructed the timber roof of the Vienna Imperial Palace using python application. This data is further processed for structural analysis within Dlubal RSTAB software (Dlubal Software) and then is imported in a BIM software for heritage documentation. Both of the above case studies have used a similar method for the creation of the 3D geometry from point cloud data. In particular, an identification of the central axes of the beams is made along with their cross sections. Furthermore, an extrusion of the cross section is formed along the corresponding axes and the result is a simplified geometry of the timber roof structure.

Limitations as regard the accuracy, the level-of-detail and the required attributes of final BIM models can be observed, especially in cases where digital information intents to be used for the maintenance and reuse of heritage timber structures. In order to tackle current challenges in this direction, a research methodology is suggested that allows automatic creation of existing timber roof frames through an algorithmic Scan-to-BIM procedure that integrates parametric and BIM environments. In contrast to previous studies, the expected advantages of the suggested methodology include:

- The development of a unified computational design framework that incorporates different types of timber roof structures.
- The ability for a much more detailed geometrical 3D model compared to previous research works where the geometry was created by extrusion leading to simplified geometries.
- The development of a data rich BIM attribute catalog for the reuse and maintenance of the timber structure.

2. METHODOLOGY

The suggested overall methodology that aims towards the establishment of a computational design approach for the recording, preservation, and reuse of timber roof structures involves three basic steps. The typological organization of timber roof systems according to their geometrical characteristics. The scan to BIM workflow for the automatic creation of 3D geometry from point cloud data, and the specification of BIM attributes that allow further actions to be taken as regard the timber roof structures under investigation.

2.1. Typological organization of timber roof structures

The typologies are related to heritage buildings but also buildings to be reconstructed and demolished with a timber roof construction. In case of heritage buildings, their structures contain irregular geometries and are experiencing deterioration through time. Due to this, it is critical to investigate them in order to preserve and maintain their architectural characteristics with minimum interventions. Usually, their timber roof structure is evident and consists of rafters or trussed rafters braced with timber battens or planks (Herzog *et al.*, 2008). The aim of the typological organization is to assist the scan to BIM methodology by organizing early in advance the capturing of existing data, the segmentation, and the creation of BIM geometry with high levels of detail according to the type of structure investigated. Furthermore, the typology of the structures and the respective geometrical data contains material and structural attributes. This allows examination of the level of maintenance in order to ensure that the existing materials could be reused and meet current building requirements.

2.2. Scan to BIM workflow

The scan to BIM workflow involves a series of steps that include a geometrical survey through TLS for capturing point cloud data, the segmentation of point clouds, the detection of the boundary points, the creation of 3D geometry from non-planar boundary lines and finally the automatic creation of complex BIM geometry. Results are followed by construction and material attributes aiming at lifecycle, environmental and cost analysis that can be considered for preservation and reuse. Figure 1 describes the aforementioned workflow in detail, also indicating the corresponding tools and software. The geometrical survey though TLS has been done using the FARO FOCUS Laser Scanner M70 (FARO Technologies Inc, 2021) that can capture point clouds. The registration of the point cloud is made through FARO SCENE software (FARO Technologies Inc, 2021) and then is imported to Agisoft Metashape software (Agisoft) for cropping and cleaning. The segmentation of the point cloud has been created in the parametric design environment of Grasshopper (Grasshopper Algorithmic Modeling), a plug-in for Rhino (Rhinoceros) using the plug-in Cockroach (Vestartas and Settimi, 2020). The point cloud is further processed within Grasshopper for the creation of the 3D geometry with the assistance of Lunchbox plugin (Lunchbox). Then, the geometry from the parametric environment has been synchronized using Rhino Inside Revit plugin (Rhino Inside Revit, 2022) within Autodesk Revit (Autodesk Inc) which is a BIM software. In the BIM platform, visualization as well as structural and construction attributes have been indicated in order to formulate an initial BIM attribute catalog for further usage.

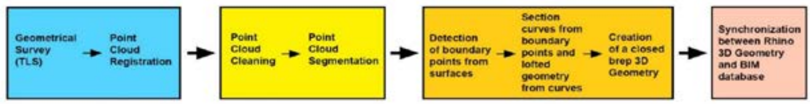

Figure 1: Scan-to-BIM workflow

2.3. BIM attributes organization

The data indicated in the previous scan to BIM workflow implements attributes that let the designer to calculate CO_2 emissions and the corresponding cost from each structural and construction component based on their material. This gives an overview for decisions to be taken in case that parts of the structure may need to be maintained, disassembled, or demolished. The expected output includes material characteristics, volume, cost per cubic meter and CO_2 emission calculations. The attributes are processed within Autodesk Revit (BIM software) using the Hawkins Brown Emission Reduction Tool (HBERT) with the corresponding material library that includes data from the Bath University Inventory of Carbon and Energy 2011 (Bowles and Jake, 2021). This toolkit allows the creation of schedules from the calculation of CO_2 emissions. It could also visualize this data into life cycle stages such as product, construction process, use stage and end of life stage according to the BS EN 15978:2011 standard. For this study, the existing timber structure is classified according to a predefined ID for each timber element including primary and secondary beams. In the pilot study presented in the next chapter, the material used from the HBERT library is "HBA_Wood-Softwood".

3. SCAN-TO-BIM DEMONSTRATION THROUGH THE PILOT STUDY OF SAINT NICHOLAS CHURCH

This paper presents a pilot study based on the abovementioned methodology that can provide useful outcomes but also can indicate limitations and potentials of the research undertaken. Future aim is the examination of a series of case studies that fall within the abovementioned framework by involving different types of timber roof structures. Within this research framework, the establishment of a data reach BIM attribute catalog is considered as an important stage for the further usage of timber roof structures under investigation. As an initial step for this paper, a heritage building with a non-regular geometry is chosen for the digital reconstruction of its timber roof. Then, the application of the specific scan-to-BIM methodology is exemplified, and finally, the accuracy deviation results as well as the required BIM attributes for the maintenance, recycling and reuse of their timber structural elements is discussed.

3.1. Saint Nicholas Church

The building is a Christian Orthodox church built in the 16th century and is located in Galata which is a village in Solea Valley, Cyprus. The church is dedicated to Saint Nicholas and it is of a great historical importance for its Architecture and Byzantine iconography (Charalambous, 2015). The building is a single-nave chapel with a gable timber roof structure.

Similar typologies can be seen in other Churches that are built from the same period in Galata. These are Panayia Podithou, Church of Theotokos or Archangel Michael, Saint Paraskevi, Saint George, and Saint Sozomenos (Constantoudaki-Kitromilidou and Diomedes, 2012). In addition, all these churches including Saint Nicholas Church, are listed as Heritages from the Department of Antiquities, Republic of Cyprus (Department of Antiquities Republic of Cyprus, 2022). In particular, the church of Panayia Podithou is listed as a UNESCO heritage (Constantoudaki-Kitromilidou and Diomedes, 2012). Figure 2 includes the gable roof of Saint Nicholas Church with the indication of the structural elements.

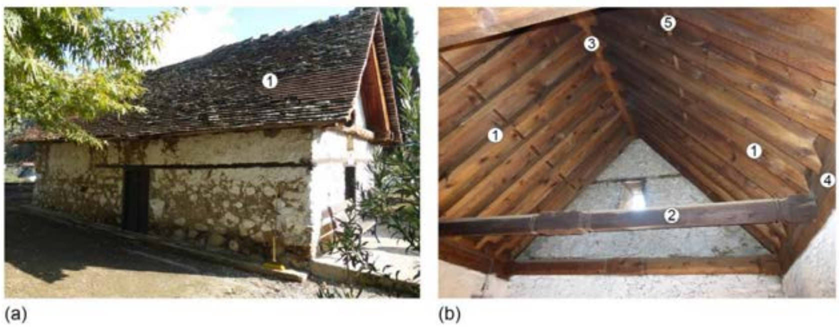

Figure 2: (a) Saint Nicholas Church, a.1. Existing gable roof and (b) Existing timber roof construction of the church, b.1. Rafter, b.2. Rafter tie, b.3. Ridge, b.4. Wall plate, b.5. Batten

3.2. TLS geometrical survey

The TLS survey is made inside the church in order to capture point cloud data of the timber structure that is visible. This allows the TLS survey to be performed without any intervention to the existing building components. In addition, it is important to avoid any obstacles such as roof lighting or furniture in order to achieve the best possible result from the survey. The internal width of the church is 3.60m and the length is 7.11m. Therefore, the laser scanner is placed in seven positions along the central axis of the space. The scanner is set at a point distance of 10 meters with 6.1mm resolution. The duration of each scan is 7 minutes and 39 seconds, and a High Dynamic Range (HDR) option is selected in order to capture texture and materiality as well. The total number of points that are captured is 192,099,256 and this is reduced to 64,608,908 after the cleaning of unnecessary elements such as the trees, the ground floor, and part of the existing walls below the structure.

3.3. Point cloud segmentation

Initially, the point cloud is downsampled to 25% which leads to 16,152,227 points to let the segmentation algorithm to work efficiently. Table 1 demonstrates the parameters for segmentation using the Cockroach plugin for Grasshopper. The first set of parameters provide 499 segments. Parts of these segments are sub-segmented in order to split the point cloud into small areas that allow the creation of groups of point clouds for each timber beam. The parameters used for the sub-segmentation are the ones described in no. 2-23. The timber rafters' segments are identified through settings 1-6 and the rafter ties from settings 7-23. The initial point cloud from the laser scanner along with the segmentation result from parameter no. 1, is indicated in Figure 3.

Table 1: Segmentation parameters

	Input						Output
Segmentation Parameters No.	No. of Points from a point cloud	Voxel Size Search	Normal Threshold Degree	Minimum Cluster Size	Color Point Cloud	Split	No. of Point Cloud Segments
1	16,152,227	0.03	2	100	True	True	499
2	4,473,201	0.02	2	100	True	True	27
3	253,104	0.03	2	100	True	True	8
4	390,194	0.04	2	100	True	True	11
5	222,968	0.04	2	100	True	True	12
6	567,836	0.05	2	100	True	True	5
7	245,770	0.021	2	100	True	True	20
8	105,841	0.015	2	100	True	True	5
9	65,891	0.015	2	100	True	True	5
10	326,044	0.04	2	100	True	True	26
11	120,555	0.04	2	100	True	True	13
12	265,343	0.03	5	100	True	True	5
13	259,212	0.02	2	100	True	True	28
14	80,186	0.015	2	100	True	True	12
15	32,396	0.02	2	100	True	True	2
16	35,625	0.01	3	100	True	True	3
17	32,669	0.01	2	100	True	True	3
18	749,620	0.04	2	100	True	True	5
19	450,197	0.01	3	100	True	True	24
20	166,115	0.03	1	100	True	True	6
21	146,362	0.03	1	100	True	True	11
22	71,939	0.03	1	100	True	True	2
23	153,120	0.04	2	100	True	True	7

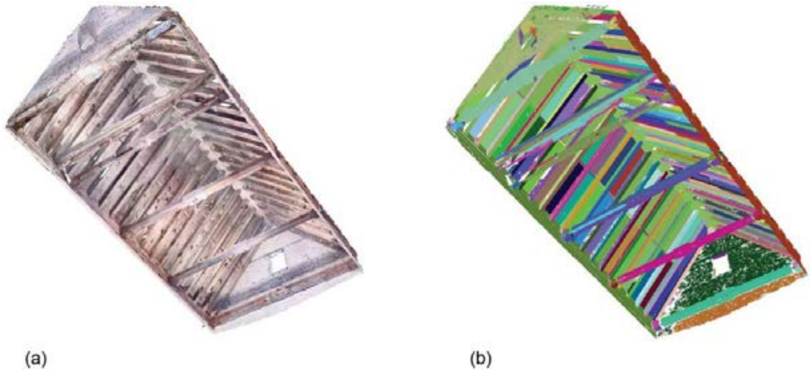

Figure 3: (a) Point Cloud from FARO laser scanner and (b) Initial segmentation result

3.4. From Point Cloud to 3D Geometry

For this study, only the primary beams that are visible from the interior are further processed. This leads to the creation of the geometry from rafters and rafter ties. As regards to the ridge and wall plate that can be seen in Figure 2, only one face is visible from the interior and therefore is not possible to create its geometry. Furthermore, their cross sections are only visible from the exterior of the church, which at the moment has not been scanned. The total number of point segments is 739, which need to be further classified in order to form groups for each timber beam. The segments representing the timber rafters are baked, allowing them to be easily set in Grasshopper and the rafter ties are classified using the list item tool. The overall result of these groups of segments provides at least three faces of each beam, which are classified as bottom face, left face and right face. Some beams that are attached to the wall can only provide two faces due to their limited visibility. In addition, some other beams were not fully scanned due to obstacles such as the iconostasis, which separates the sanctuary from the nave and lighting fixtures from the ceiling. The segmented rafters and rafter ties can be seen in Figure 4 along with an example of a group of point segments for a timber rafter.

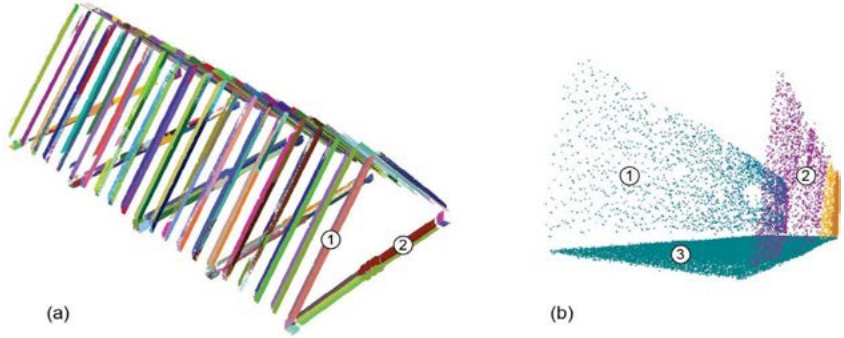

Figure 4: (a) Point cloud segmentation of timber structural elements, a.1. rafter, a.2. rafter tie (b) Point cloud of a rafter, b.1. left face, b.2. right face, b.3. bottom face

In order to further proceed with the development of Boundary Representation (BREP) geometry, the point cloud of each group of beams is exploded to points with XYZ coordinates. These points are processed using the convex hull tool that identifies the boundary of each cloud. Furthermore, the boundary along with the points are imported into the patch surface tool that allows the creation of the geometry from each of the beam faces separately. These faces are untrimmed, and then their intersection forms the non-planar boundary curves of each beam that is divided into boundary points. The points along with the initial points from the cloud are merged and patch geometries of the faces are recreated. This allows the generation of a much more detailed geometry of the faces. The bottom central axis is also detected and rectangular planes perpendicular to that axis are formed. The planes, which are numbered from 100 to 300 for each beam depending on the type of geometry, are intersected with the geometry of the faces. This lets to the formation of boundary points along the edge of the faces. Subsequently, at least 100 to 300 irregular section curves of each beam are created, which follow the geometry of the existing structure. Moreover, a lofted surface is created out of these curves, which could further be processed for the formation of a closed BREP geometry. This algorithmic process is described in Figure 5. The result is the development of any timber beam with irregular geometry, which is close to the as-built condition.

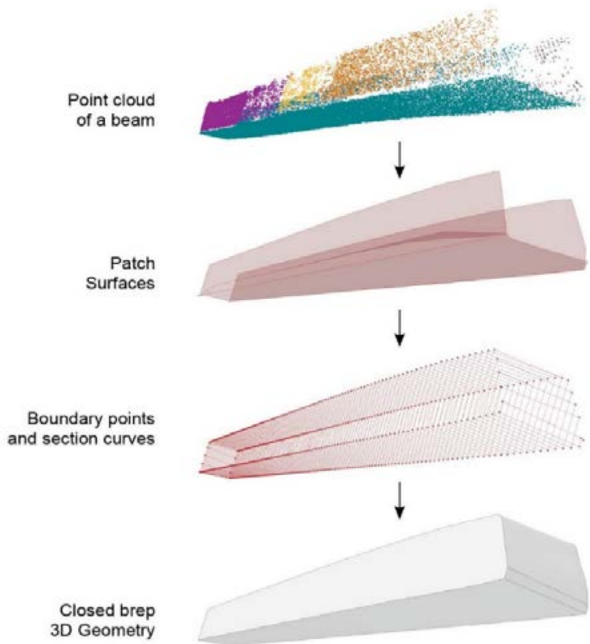

Figure 5: Algorithmic process from point cloud to 3D Geometry

3.5. Quantitative and qualitative evaluation of the computation approach

In order to evaluate the deviation of the 3D geometry compared to the point cloud, the Volvox plugin (Evers and Zwierzycki, 2016) for Grasshopper is used. Figure 6 demonstrates the accuracy evaluation results that range between -88mm (purple color) to 92mm (red color). As it can be seen, there is a significant deviation with an average between -88mm to 92mm in the rafter ties due to the fact that their cross section is octagonal, but the generated geometry is simplified to a rectangular cross section. Furthermore, the rafters have an average deviation between -7.7mm to 9.2mm. This indicates a higher accuracy value than the rafter ties due to the efficiency of the algorithm to generate 3D geometry of timber beams with a rectangular cross section.

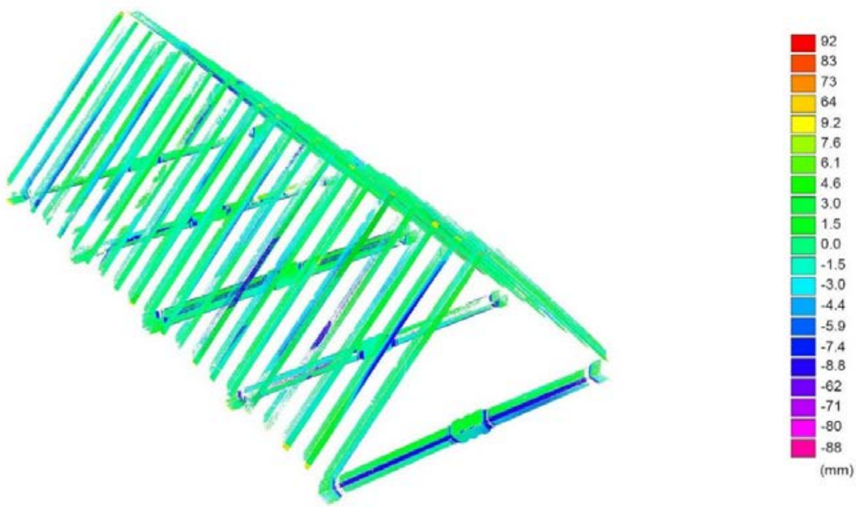

Figure 6: Point cloud deviation with color bar indicating minimum to maximum values

3.6. Synchronization of 3D geometry with BIM software

For the synchronization of the 3D geometry with a BIM environment, Rhino Inside Revit plugin is used within Autodesk Revit. Specifically, the "Geometry Direct Shape" tool is used, with inputs such as the category which is structural framing, the 3D geometry, and the corresponding material. The existing structure of the church is made of pine timber and therefore the BIM material chosen from the HBERT library is "HBA_Wood-Softwood". Furthermore, an ID is set for each beam using the "Define Parameter", "Add Parameter" and "Element Parameter" tools. The ID is set as Timber Beam (TB) followed by the number of each beam. Moreover, through the HBERT toolkit in Revit, the volume of each material along with CO_2 emission calculations are visible from the schedule generated. In addition, an indication of the cost per cubic meter is also available for each material. The total number of timber beams created are 47 in which 42 are rafters and 5 are rafter ties. Due to scanning issues mentioned in chapter 3.4, the volume of 11 out of 47 beams could not be set from Rhino to Revit and therefore a calculation could not be possible. The BIM geometry can be seen in Figure 7 and the corresponding attributes in Table 2.

Figure 7: BIM Geometry, (a) Top perspective view and (b) Roof Plan

Table 2: BIM Attributes

ID	Material: Name	Material: Volume	Total Cost per m3	Overall Embodied Carbon sum (tonCO2e)
TB01	HBA_Wood - Softwood	0.11 m³	€ 183.15	0.019935
TB02	HBA_Wood - Softwood	0.07 m³	€ 120.56	0.013122
TB03	HBA_Wood - Softwood	0.06 m³	€ 99.07	0.010783
TB04	HBA_Wood - Softwood	0.12 m³	€ 200.92	0.021869
TB05	HBA_Wood - Softwood	0.11 m³	€ 180.57	0.019654
TB06	HBA_Wood - Softwood	0.02 m³	€ 36.89	0.004015
TB07	HBA_Wood - Softwood	0.02 m³	€ 35.29	0.003841
TB08	HBA_Wood - Softwood	0.02 m³	€ 35.53	0.003868
TB09	HBA_Wood - Softwood	0.02 m³	€ 30.36	0.003304
TB10	HBA_Wood - Softwood	0.02 m³	€ 28.78	0.003132
TB11	HBA_Wood - Softwood	0.02 m³	€ 32.52	0.003539
TB12	HBA_Wood - Softwood	0.02 m³	€ 35.98	0.003916
TB13	HBA_Wood - Softwood	0.02 m³	€ 36.78	0.004003
TB14	HBA_Wood - Softwood	0.02 m³	€ 35.32	0.003844
TB16	HBA_Wood - Softwood	0.02 m³	€ 37.28	0.004058
TB17	HBA_Wood - Softwood	0.02 m³	€ 36.98	0.004025
TB18	HBA_Wood - Softwood	0.02 m³	€ 35.19	0.00383
TB19	HBA_Wood - Softwood	0.02 m³	€ 36.01	0.003919
ID	Material: Name	Material: Volume	Total Cost per m3	Overall Embodied Carbon sum (tonCO2e)
TB20	HBA_Wood - Softwood	0.02 m³		0.00372
TB21	HBA_Wood - Softwood	0.02 m³	€ 34.45	0.003749
TB22	HBA_Wood - Softwood	0.02 m³	€ 34.11	0.003713
TB23	HBA_Wood - Softwood	0.02 m³	€ 33.25	0.003619
TB26	HBA_Wood - Softwood	0.02 m³	€ 35.91	0.003909
TB27	HBA_Wood - Softwood	0.02 m³	€ 40.33	0.00439

TB28	HBA_Wood - Softwood	0.02 m³	€ 33.89	0.003688
TB29	HBA_Wood - Softwood	0.02 m³	€ 33.26	0.003621
TB31	HBA_Wood - Softwood	0.02 m³	€ 33.99	0.0037
TB32	HBA_Wood - Softwood	0.02 m³	€ 34.55	0.003761
TB33	HBA_Wood - Softwood	0.02 m³	€ 33.64	0.003662
TB34	HBA_Wood - Softwood	0.02 m³	€ 34.23	0.003726
TB37	HBA_Wood - Softwood	0.02 m³	€ 32.73	0.003563
TB38	HBA_Wood - Softwood	0.02 m³	€ 34.02	0.003703
TB39	HBA_Wood - Softwood	0.02 m³	€ 36.04	0.003923
TB40	HBA_Wood - Softwood	0.02 m³	€ 37.21	0.00405
TB43	HBA_Wood - Softwood	0.02 m³	€ 34.99	0.003808
TB47	HBA_Wood - Softwood	0.02 m³	€ 37.88	0.004123

4. CONCLUSIONS

This research study has demonstrated and discussed the first results of a scan-to-BIM methodology that aims at the digital reconstruction of timber roof structures of existing buildings for their future maintenance, recycling, and reuse. Specifically, a pilot study that examines the reconstruction of the timber roof structure of a heritage building is presented. Starting from the TLS survey, an automated method for segmenting, 3D generating and evaluating the results compared to the point cloud is demonstrated. Then, discussion on the potential of developing a data reach BIM attribute catalog is drawn. Preliminary results derived from scan-to-BIM approach show great potential for its effective application in digital reconstruction due to the low deviation values achieved. Specifically, the evaluation of average deviation values that range between -7.7mm to 9.2mm for the rafters, indicate that the 3D geometry is highly accurate and close to the as-built geometry in case of beams with rectangular cross sections. In the case of rafter ties with octagonal cross sections the average deviation values that range between -88mm to 92mm show that further investigation is necessary both in scanning and in 3D modeling stage. Also, the automated transferring and synchronization of 3D geometry from the parametric environment to the BIM environment provides a platform for data development that can lead to further processing. The potential for calculating CO_2 emissions along with the corresponding cost for each timber beam provide us with BIM attributes that allow decisions to be made as regards the preservation, recycling, and reuse of existing timber elements. Future studies may include additional laser scans in the interior of the church, in order to capture the missing volume of the geometry from 11 beams that could not be calculated in BIM. In addition, further laser scanning could be done on the exterior of the church, for achieving the generation of 3D geometry of more timber structural elements such as the ridge, wall plate and battens.

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USE OF BIM MODEL IN OUTSOURCING FACILITY MANAGEMENT SERVICES

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ABSTRACT

With a certain number of resources at their disposal, many organizations are choosing to narrow their specialization to push further boundaries in efficiency and the level of services offered. For this reason, opportunities are sought to outsource tasks that are not related to the core business of the institution. Outsourcing is becoming increasingly popular bringing many benefits to the enterprise. Building operation and maintenance, broadly defined, is an area where there are many tasks that can be transferred from the employees of a given enterprise to an external company for optimization purposes. Building Information Modeling (BIM) is also synonymous with optimization, and as a tool suitable for use throughout the life of a building, it can also be helpful in property management. The more complex the building complex, such as a university, the greater the number of potential applications and the greater the number of potential profits. The article examines the reasons for and benefits that outsourcing can have for building management, like reducing the costs, allocation

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of the resources held to the main activities, improving the quality of services provided, or lack of qualification and knowledge among members of in-house teams. It also analyzed the scope of information that can be included in a BIM model in the perspective of its reuse for building management using Level of Detail (LOD). Outsourcing and BIM was put together in the context of building maintenance and analyzed within various aspects of how to support the process of outsourcing building maintenance tasks using the BIM model. Among other things, it can support in creating of several types of inventory searches, finding individual devices in a facility and finding the shortest route to them, and presenting all the information in a clear graphical form. Having a digital twin of a building also comes with such responsibilities as the need to constantly update the model and to keep a minimum LOD.

Keywords: BIM; Building Information Modeling; Facility Management; Operation and Maintenance; outsourcing in BIM

1. INTRODUCTION

The maintenance of a facility is a process that happens in the background, beyond its main activities, so the users of the building may be unaware of the conduct of, for example, various maintenance and repair activities. Undeniably, good building management determines the proper functioning of any institution, no matter whether it is a public or business sphere. Defining facilities management as covering all activities that are not related to the core business of a given organization, we can find such examples as cleaning services, security, technical maintenance, care of plants and green areas, parking management, air conditioning maintenance, document administration services, maintenance of fire safety systems, waste disposal management and taking care of the decoration.

(Tannor, Attakora-Amaniampong and Appau, 2022). It is not easy for an organization to conduct all these activities, as it sometimes becomes very costly to maintain dedicated departments for each of these aspects of the building lifecycle. If the question of optimizing building life processes arises, the use of building information modeling (BIM) is increasingly being explored, as its capabilities extend far beyond the design phase and obtaining a building permit. There is growing recognition of the benefits that the use of building information modeling can bring to property management.

2. OUTSOURCING OF FACILITY MANAGEMENT SERVICES

Facilities management (FM) is important in maintaining a user-friendly environment for facilities, where the highest quality services can be provided to consumers while maximizing return on investment (Ikediashi, 2014; Atkin and Brooks, 2015; Masjoni, 2015)w którym mogą być świadczone usługi o najwyższej jakości dla konsumentów, a jednocześnie maksymalizowany jest zwrot z inwestycji (Masjoni, 2015. Most buildings still use traditional management, which includes a small team that focuses solely on the functionality of the building's facilities and services, such as the maintenance department, which ensures that all equipment is always in working order (Kurdi *et al.*, 2011). Observing the business domain, where financial efficiency is one of the key markers of success, in times of greatest challenges, e.g.: during a market crisis, even the richest of firms consider reducing costs to stay in business (Kurdi *et al.*, 2011). In the general sense, it is not profitable for a building owner to employ building maintenance team members in-house. Work such as cleaning, performing ongoing maintenance, and maintaining fixtures are outsourced to specialized teams outside the firm. Ying Fan (Fan, 2000) defines outsourcing as a contract between a customer and one or more suppliers to provide services or processes that the customer currently performs internally. As the main difference between outsourcing and any other purchasing agreement is that the customer outsources part of its existing internal operations. Facilities management is increasingly being recognized as part of the business process, and management performance has a noticeable impact on performance metrics that directly relate to core business values (Brackertz and Kenley, 2002). Outsourcing of facilities management services not only releases a company from dealing with tasks outside its core business, but helps reduce expenses (Jennings, 2002). If a task does not require continuous work and thus does not fill a full-time position, outsourcing it most often can be a cheaper solution than having it performed by a full-time person, since the higher labor cost of outsourcing the task is still a more favorable solution for the firm than maintaining a position that does not have a 100% workload. Focusing one's resources on achieving good results in core activities is one of the key factors that give a competitive advantage (Bredeson and Maechling, 2005). There are many reasons why a firm may choose to outsource. Although the reasons are usually specific to a particular situation, some commonly cited reasons are as follows (Jennings, 2002; Ikediashi, 2014; Cui and Coenen, 2016)the customer's perspective is used to identify the dimensions and drivers of relationship value. Design/methodology/approach – A three-stage research design was used. The first stage was a thorough literature review, followed by expert interviews with six senior managers from the customer side, together with workshop and discussion with FM academics. In the third stage, quantitative data were gathered in a survey of 60 senior managers whose companies outsourced FM services. Findings – Findings show that relationship value is an antecedent to relationship quality of the business relationship in the context of FM. In all, 9 dimensions and 34 drivers of relationship value were identified, and a framework of relationship value for FM was established and measured. The sacrifice dimension correlates positively with relationship value, which contrasts with previous studies of relationship value in the context of business markets. Research limitations/implications – A framework of relationship value has been established for further in-depth investigation. There are limitations related to the sampling procedure: qualitative research selected large-sized organizations; the relationship value was only studied within the customer–FM supplier dyad; and a static view of customers' perceived value from the relationship with their FM suppliers. Practical implications – The study provides a set of value dimensions and drivers for customers to assess how a FM supplier adds value in a relationship, and for FM suppliers to improve their services. Originality/value – This research narrowed the gap in relationship-value studies in FM. The findings can contribute to traditional theory that customer value can be the add-on between benefits ("what you get":

- reducing the costs,
- allocation of the resources held to the main activities,
- improving the quality of services provided,
- lack of qualification and knowledge among members of in-house teams,
- lack of appropriate technologies,
- increase flexibility in responding to market conditions,
- ease the implementation of changes in the organization.

In addition, putting tasks in the hands of outsourcers in a business--to-business (B2B) system makes it easier to enforce the expected result of the outsourced work. If the results are unsatisfactory, the outsourcer can change the subcontracting firm. In addition, the building owner has no influence on the assignment and rotation of employees to work in the building.

3. LEVEL OF DETAIL (LOD) IN BIM

In the most general terms, a BIM model reflects the spatial structure of a building in digital form. In a bit more precise terms, the building model should reflect the level of detail (LOD) agreed upon among project participants. The purpose of the LOD is to define the amount and level of detailing of building information that must be included in the BIM model (Kolarić, Vukomanović and Ramljak, 2022). In addition to physical properties and graphical objects, this includes object-related data. Generalizing Level of Detail (LOD) is a guideline that is used to more precisely describe the required level of sophistication of a BIM model, which greatly improves coordination and information sharing between project teams. The LOD scale has 6 levels: 100, 200, 300, 350, 400, and 500, which is shown in Figure 1. as an example of the different possible levels of detailing of wall construction information.

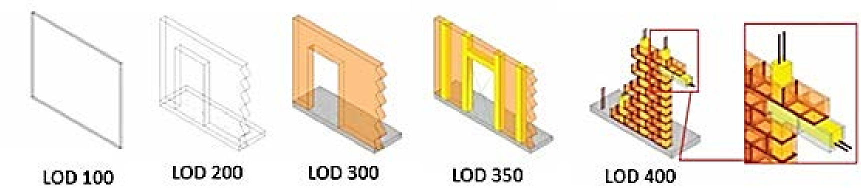

Figure 1: The wall model in LOD 100-400 (BIMForum, 2015). LOD 500 mentioned in the paragraph above, is not shown as it does not differ in the level of information from 400, but only in the moment of execution.

The lowest value, 100, refers to the lowest, conceptual accuracy, in which the model is represented by general shapes and symbols. The main solids of the project have only approximate shapes, sizes, and locations. With the help of LOD 100, it is possible to show the general idea and spatial relationships of the largest elements in the design, which are enclosed in so-called bounding areas, usually with a cuboid shape. The elements of the model in LOD 200 are still represented visually as a general extent system, object, or assembly and still have approximate specifications, number, size, shape, placement, and orientation, but the individual elements can already be distinguished. The 300 level can be associated with construction documentation, that is, the elements will have the exact size, quantity, location and orientation specified. Level 350 has a degree higher accuracy, as it includes details that show how the building elements interact with the various systems. LOD 400 accurately represents the designed building. The last level of accuracy is LOD 500, which represents the building as it was built, that is, with the location of all designed elements verified on site (United-BIM Inc., no date). Elements can also have some characteristic data assigned to them:

- basic information, among which is the name of the item, image, BIM model,
- information about a specific product, that is, for example, serial number, date of purchase, responsible person,
- detailed geometry, i.e., size, material, details,
- service history, logs, and entries made by service personnel,
- additional information, such as instructions, warranty, or installation method.

A well-prepared BIM model can become a centralized repository of much of the information needed during the life of a building (Pishdad-Bozorgi *et al.*, 2018). Easy access to this information can greatly improve building maintenance. Many researchers point to LOD 500 as suitable for use in building maintenance tasks (Bruno, De Fino and Fatiguso, 2018; Chen *et al.*, 2018), although at the same time it is indicated that models with this accuracy are rare (Pärn, Edwards and Sing, 2017). There are also attempts to determine the degree of accuracy for different parts of the model to best fit it for maintenance and upkeep (Alavi and Forcada, 2019) holds undeveloped possibilities for supporting Facility Management (FM. With such a building model in place, the manager must also take proper care of its maintenance in the form of updating all changes made.

4. OUTSOURCING SUPPORTED BY BIM

The idea of using the BIM model during the use of a building is that it can be treated as a database for which specific queries are created. Examples of queries:

- quantity statements, collecting how many elements in the building meet a given criterion, e.g.: it could be light bulbs of a given wattage or the number of chairs in the rooms,
- area statements, which allow you to see how much area of floors with a given surface or the surface of walls that need repainting,
- volumetric lists if the following is required, for example, installation of air conditioning.

Such queries speed up the inventory of building equipment and the creation of cost estimates.

In addition, the BIM model can be used to find and locate building equipment, such as HVAC systems and plumbing, electrical, and gas systems. Without the use of BIM, workers use paper documentation or rely on their experience, intuition, and personal judgment (Becerik-Gerber *et al.*, 2012)and thus has extensive information require- ments. While some of these needs are addressed by several existing FM information systems, building information modeling (BIM. According to participants in the construction process, the most common are problems with finding: information about the MEP, specifications and warranty, operating parameters of equipment and information about spare parts, as well as their make, model and instructions for use, information about the history of work orders and current as-built plans (Liu and Issa, 2013)it holds undeveloped possibilities for supporting Facility Management (FM. A facility's technical equipment is most often hidden in such a way as to be invisible to facility users, in places such as floors, ceilings and walls. While this is an understandable approach, it can cause some problems in the service process. Quickly locating equipment becomes crucial, especially in emergency situations. An example of this is shown in Figure 2. A part of the floor plan of the conference center building with the water tank located.

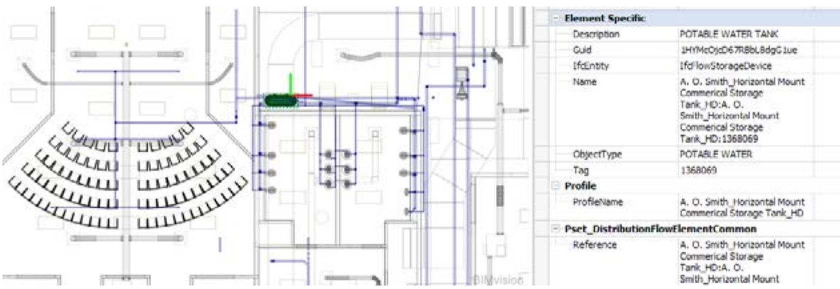

Figure 2: Location of the water tank on the floor, with additional information included in the BIM model. The model viewed in the BIMvision viewer. Prepared using the OTC Conference Center building model provided by Autodesk Inc. (Autodesk, 2022).

The flexibility mentioned in paragraph 2. in the choice of contractors provided by outsourcing has the disadvantage that a service order may be given to a company that is unfamiliar with the facility and will be dealing with it for the first time. Thus, when introducing a new people to the facility either an external specialist or a new member of the management team, it is necessary to somehow indicate to them the location of the element in question. The structure of buildings can also sometimes be quite complicated and navigating through them sometimes causes problems. It also happens that an element has been replaced or moved without the knowledge of the maintenance team. With a BIM model at his disposal, the building manager can create graphic materials showing where a particular element is located. It is also possible to plot the shortest route to a given point, e.g.: from the entrance, or to plot the most optimal route taking into account a visit to several points in the facility. Thanks to this, the ordering party gets the possibility to create and handle the order largely without any contact. It is also a certain saving of resources, as it does not require delegating an employee to assist an external technician in moving around the facility.

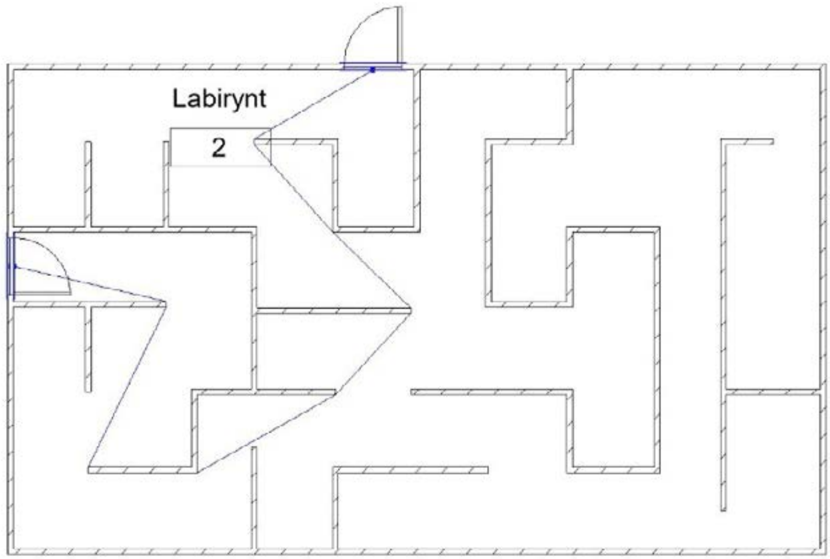

Figure 3: Determining the shortest route between the entrance and exit to a room using a BIM model.

Determining the shortest route in a building using a BIM model, as shown on Figure 3., can also be used by fire protection specialists who develop building evacuation plans. The availability of a 3D model greatly speeds up and enhances the ability to conduct analyses.

In the event of a failure or planned maintenance of a building component that requires access from one of the usable rooms, the BIM model can also be used to manage building spaces. One can easily find a vacant room with similar characteristics, such as: the number of desks or chairs, and move employees to such a room for the duration of maintenance activities, so as not to cause unnecessary interruptions.

Having a BIM model, it can be shared with designers and can also be used when redesigning interiors. This is a way to reduce the costs associated with the initial inventory, which interior architects then don't have to do, especially if visualizations showing the design are then made based on the 3D model. Using a 3D model can also reduce the number of pre--design site visits, further reducing costs.

In addition, the BIM model can be used to perform energy simulations when looking for methods to optimize a building's primary energy demand. Changes in thermal insulation or heating source can be simulated relatively quickly.

In addition, when using a BIM model, which is often referred to as a digital twin, this model should also be updated to reflect reality. Therefore, any maintenance work should be reflected in the BIM model. When it comes to BIM design software, there are most often two categories of programs - those for editing and those for viewing the contents of the model. The first usually appear as paid commercial versions, while the second is largely freely available to the public at no cost. So, while viewing content or processing it should not require a property manager to be remarkably familiar with new software or pay a lot of money, editing files is different. Therefore, another aspect of BIM outsourcing is outsourcing the making or updating of an existing BIM model (Lin, Hsu and Hu, 2022). Since benefiting from BIM technology is not reserved only for newly constructed buildings, BIM documentation of an existing building can also be commissioned. This can involve inventoried the building right away using BIM, but also converting the 2D documentation you have into a 3D model, raising the LOD of the BIM model you have, or creating a visualization of the building.

Given that any of the building's elements may require service interventions, the optimal LOD for a BIM model used in outsourcing would be LOD 500. It then gives real-time access to several types of information that may be needed while performing tasks in the building. Requiring a minimum of the ability to precisely locate building elements, the minimum here is LOD 300, which takes into account the design quantity and location of elements and compared to LOD 500 may not include less important connections between elements or changes that have occurred during construction. It therefore carries the risk that some elements may be more difficult to locate.

5. SUMMARY

There is a noticeable trend nowadays to narrow the specialization of companies' activities to improve the quality of their services and optimize the use of their resources. A BIM model prepared during construction or as an inventory of an existing building can be a valuable tool in the building management process also in the context of outsourcing maintenance and repair activities. From the most desirable LOD 500 to the minimal LOD 300, the BIM model can be successfully used to prepare more precise service orders. It can be used to create several types of statements estimating the number of resources needed, as well as graphic materials indicating the location and route of access to various locations in the building.

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EXPLORING ARCHITECTS' PERSPECTIVE ON THE DIGITAL WORLD USING PPT FRAMEWORK

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ABSTRACT

Architects' position is altered due to the emerging digital frameworks, processes and technologies in the Architecture Engineering and Construction (AEC) industry.

Architects communicate and collaborate by using language of design (Schön, 1983). Nowadays this communication is often expressed through BIM-based tools. These tools together with emerging digital frameworks like Virtual Design and Construction (VDC) impact the interdisciplinary collaboration and knowledge transfer in the AEC industry (Slotina, 2021)engineering and construction industry (AEC. Although architects have an important role in the AEC industry, their representation in VDC-courses in Norway over the last three years was around 3%.

This raises the question whether architects are aware of how digital frameworks are affecting the interdisciplinary way they collaborate? And are digital frameworks like VDC supporting the way architects conceptualize design?

This study uses semi-structured interviews with seven architects to look at the architect's self-perception on the way they are conceptualizing design. The interviews are analysed using People, Process and Technology (PPT) framework based on Owen (2013). The analysis of PPT shows that technology dominates in relation to architects' way of conceptualizing design in the VDC framework.

For the digital frameworks to improve the collaboration for architects in interdisciplinary teams, it should take into the consideration the processes architects go through when they conceptualize design. Digitalization processes like Building Information Modelling (BIM) changes the way architects conceptualize and design buildings (Abdelhameed (2006), Hermund (2009)but are there other problems with the implementation of BIM as a formulized system in a field that ultimately is dependent on a creative input? Is optimization and economic benefit really contributing with an architectural quality? In Denmark the implementation of the digital working methods related to BIM has been introduced by government law in 2007. Will the important role of the architect as designer change in accordance with these new methods, and does the idea of one big integrated model represent a paradox in relation to designing? The BIM mindset requires changes on many levels.","container-title":"Computation: The New Realm of Architectural Design [27th eCAADe Conference Proceedings / ISBN 978-0-9541183-8-9] Istanbul (Turkey, Shen et al. (2010)). This causes distress as the design issues are being solved "on the spot" (Slotina, 2021)engineering and construction industry (AEC.

Architects' awareness of digital frameworks like VDC affects how architects can contribute to the development of those frameworks. This research shows how architects can improve the balance of people, process, and technology in new emerging digital frameworks.

Keywords: Virtual Design and Construction (VDC); PPT - People, Process and Technology; Architecture, Engineering and Construction (AEC) Industry; BIM – Building Information Modelling; Digitalization Processes; Interdisciplinary Collaboration

1. INTRODUCTION

Architectural building projects depend on a successful collaboration, cooperation and knowledge sharing between various expert groups. Over the years Architecture, Engineering and Construction (AEC) industry has been developing different strategies to do so. Though with the digital development in Computer Supported Cooperative Work (CSCW) and computer-aided design (CAD) in the mid-1960s, technology has gained an important role in the architectural project development.

The technology itself though cannot fully provide the industry a complete framework to work towards. Collaborating people and integrated processes is also something that needs to be addressed (Owen, 2013) in order to have a holistic framework for the AEC industry.

There have been several attempts to mobilize AEC industry. Some examples reviewed by Shen et al. (2010) – FIATECH (Fully Integrated and Automated TECHnology) organization and the ECTP - the European Construction Technology Platform project. The newest digital framework to facilitate the processes of sharing, cooperation, and collaboration as well as information and knowledge transfer is Virtual Design and Construction (VDC) with one of its main technologies – Building Information Modelling (BIM). VDC is a digital framework for AEC industry experts that helps to use BIM technology, establishes processes for the building project and facilitates to define clear client and project goals right at the beginning of the project.

Drawing upon previously conducted field studies and an ongoing PhD study a research gap was identified by the authors (Slotina, 2021) engineering and construction industry (AEC, ‘the impact on expert collaboration in the Architecture, Engineering and Construction (AEC) industry through VDC, and how this affects the processes of interdisciplinary team interaction through Virtual Design and Construction (VDC) framework’.

This paper aims to look at architects’ perspective on digital frameworks like VDC and how they have affected the way architectural projects are being developed.

2. CURRENT STATE OF THE ART – SOTA

Architectural discipline & creativity

This part of the paper focuses on the expert culture specific to Architecture. Architects’ creative processes include collaboration with other experts from AEC industry - clients, consultants, and contractors. As part of their daily work, architects create buildings while considering the social and physical surroundings (Murphy, 2005). This means that creativity forms an important part of their working lives. Tanggaard (2013) highlights that, “creativity is an everyday phenomenon resulting in continual processes of “making world”” (p. 20).

Although there is a growing amount of research on the architectural expert cultures (Schön, 1983; Murphy, 2005; Tanggaard, 2013; Gade et al., 2019; Van der Linden et al., 2019)talk, and graphic representation in architectural practice”,”title-short”:”Collaborative imagining”,”volume”:”2005”,”author”:[{“family”:”Murphy”,”given”:”Keith M.”}],”issued”:{“date-parts”:[[“

2005"]]}}},{"id":446,"uris":["http://zotero.org/groups/2581169/items/49DG9-2HR"],"itemData":{"id":446,"type":"article-journal","abstract":"This paper explores the sociomateriality of creativity in everyday life. Whilst creativity research has traditionally been concerned with the intellectual and i...","archive_location":"Sage UK: London, England","container-title":"Culture & Psychology","DOI":"10.1177/1354067X12464987","language":"en","license":"© The Author(s, Schön (1983) also raises the fact that the boundaries of the architectural profession are continuously shifting and therefore the study of the architectural profession also can be challenging. Nowadays an architectural office might have several experts that all go under the title "architect", but specialise in a certain project typology, project phase or a technological specialisation.

Tanggaard (2013) provides a helpful suggestion for architectural creativity. Creativity is present within every individual, but when researching creativity in architecture the material basis needs to be taken into consideration as well as that there is a need to understand the sociomaterial aspects of creativity. With that she means that creativity should be connected to everyday life and that materials form an important part in supporting creativity as design. Tanggaard (2013) highlights that designs are not realized without being materialized on paper or computer in the same way that an architectural project does not materialise to become a house without building materials.

Drawing and talking in parallel is what Schön (1983) defines as *language of designing.* We return to this concept later in the findings and discussion part of the paper.

Digitalisation processes in architecture & VDC

Although one might think humans and society are separate from the technological development, people are much more entangled with the surrounding technologies. Today's humans are part of a technological civilization (Bauchspies et al., 2005). Bauchspies et al. (2005) raises a point that the strength of technology is often recognized by those who can change and amend the technology and not only use it.

This results in different perceptions users and creators might have about technology. The most popular technologies nowadays are computer supporting data processing systems also called information systems. Whatever profession is chosen, whether a person wants to be a graphic artist, architect, nurse, lawyer, he/she will have to work with or through information systems in some ways and become knowledgeable in the use of information system (Laudon and Laudon, 1998).

"Information system (IS) can be defined as a set of interrelated components working together to collect, retrieve, process, store, and distribute information for the purpose of facilitating planning, control, coordination, analysis, and decision making in businesses and other organizations" (Laudon and Laudon, 1998, p. 6).

In the mid-1960s, a particular kind of Information System (IS) emerged – computer-aided design (CAD) technology - which refers to all types of computer programmes that can help with design and engineering work (Crotty, 2012)betweenpartieswith different professional backgrounds trying toachieve a very complex goal.Under these difficult circumstances,the quality of information on which projects are based should be of the highest possible standard. Theline-based, two dimensional drawings on which conventional construction is based render this all but impossible. This is thesource of somemajor shortcomings in the construction industry, and this book focuses on the two most fundamental of these: the failure to deliver projects predictably: to the required quality, on time and within budget; and the failure of most firms in the industry to make a survivable level of profit. By transforming the quality of information used in building, BIMaims totransform construction completely. After describing and explaining these problems, the way in which BIM promises to provide solutions is examined in detail. A discussion of the theory and practice of BIM is also provided, followed by a review of various recent surveys of BIM usage in the US, UK and selected European economies. The way in which other industries, including retail andmanufacturing, have been transformed by information are explored and compared with current developments in the deployment of BIM in construction. Five case studies from the UK show how BIM is being implemented, and the effects it is having on architects and contractors. This book isperfect for any construction professional interested in improving the efficiency of their business, as well as undergraduate and postgraduate students wishing to understand the importance of BIM.”,”edition”:”1st”,”event-place”:”New York, NY, 10001”,”ISBN”:”0-415-60167-3”,”publisher”:”Routledge”,”publisher-place”:”New York, NY, 10001”,”source”:”ACM Digital Library”,”title”:”The Impact of Building Information Modelling: Transforming Construction”,”title-short”:”The Impact of Building Information Modelling”,”author”:[{“family”:”Crotty”,”given”:”Ray ”}],”issued”:{“date-parts”:[[“2012”]]}}}],”schema”:”https://github.com/citation--style-language/schema/raw/master/csl-citation.json”} . Later a 3-dimensional modelling technology developed called Building Information Modelling (BIM). One could argue that BIM is becoming the sociomaterial aspect of the everyday architectural work.

Building information models are one of the main technology drivers of the building projects to share information and communicate between different teams and experts including architects, contractors, builders, building owners etc. This “free-flow” information does not necessary solve the communication and collaboration issues (Slotina, 2021)engineering and construction industry (AEC. To go further Wong et al. (2009) argued that the effectiveness of BIM is hard to measure, because routines are established by different companies in different ways, methods like Integrated Concurrent Engineering (ICE) are emerging in construction industry. ICE is a social method, helped by technology, to create and evaluate multidiscipline, multi-stakeholder virtual design and construction (VDC) models extremely rapidly (presentation by Anthony Kunz, 2013).

Digital frameworks like VDC attempts to integrate digital tools like BIM and systemize the collaboration processes. The main parts of VDC include multi-disciplinary BIM models and explicit objectives of the project and the client (Kunz and Fischer, 2020), illustrated in the Figure 1.

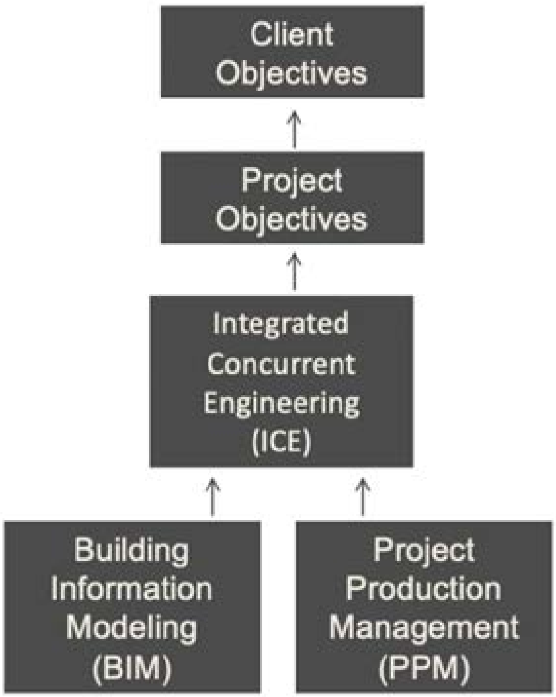

Figure 1: VDC Framework (Hjelseth and Fischer, 2021)

Figure 1 illustrates how BIM directly supports coordination for the design process: Integrated Concurrent Engineering (ICE). Project Production Management represent the project planning and scheduling activities. Project objectives represent the desired built solution, and Client objectives represent the impact of the user of the built solution. To achieve both type of objectives, architects play a high importance in the interdisciplinary team. It is therefore interesting to explore the "new" role of the architect in these new constraints for collaboration.

A study by Gustafsson et al. (2015) describes the potential impact of VDC as: *"The increasing use of Virtual Design and Construction, VDC, is changing the way of working in the construction industry. With the introduction of VDC follows the creation of new roles and new ways of communicating within construction projects". -... "Finally, the results show that there is demand for higher involvement of VDC professionals as compared to their current involvement."* Our study intends to explore architect's role in VDC and digital frameworks alike.

Conclusion on the SotA

As the architect profession has diversified and shifted over the years (discussed in Schön, 1983), the new sociomaterial aspects of the profession has been revealed – digital tools for BIM, visualisation, artificial reality - AR, virtual reality – VR, film making, prefabrication, project management and many more. As the possibilities of these technologies has mainly intrigued architectural profession, many architects have engaged with those technologies rapidly. Although as mentioned above the access and engagement in technology and BIM does not necessary lead to a better collaboration interdisciplinary (Slotina, 2021)engineering and construction industry (AEC. Digital frameworks like VDC aims to have a more holistic approach to building project development. There is close to no research done on architects' perspective on VDC and how they presume it affects their everyday work. Therefore, that is what this paper aims to investigate.

3. METHODS

For this conference paper, three main methods were deployed: (1) further literature review, (2) field observations on VDC course at NTNU (3) semi-structured interviews and analysis of the interviews to reveal the architects' point of view regarding the effects of VDC on the architectural projects.

Based on techno-anthropological investigation methods, this study mainly used qualitative research methods. Qualitative methods can often be viewed as relying only on narrative results, however these descriptions produce rich, explanatory, meaningful information and explain in detail human actions (Abdelmohsen, 2011)rules and attributes about a design product and process for Architecture-Engineering-Construction (AEC.

Techno-Anthropological investigation is formed by identifying the transitional, transformational and hybrid spaces that may occur as a result of (1) getting a sense of existing and/or different expert cultures and how they are shaped by technology; (2) analysing and understanding the nature of the technologies in use (Børsen and Botin, 2013)(see figure 2). This is achieved by gaining insight into the cultures, society and humanity and the study of personal and the intimate details that are then compared to identify generalities (Eriksen, 2004).

The goal of the field observations was to gain the background knowledge on how the VDC framework is being taught to the AEC industry as well as to gain the contact to the possible informants from different expert groups. The observations were structured as part of a focused ethnography. Focused ethnography uses shorter field visits as the

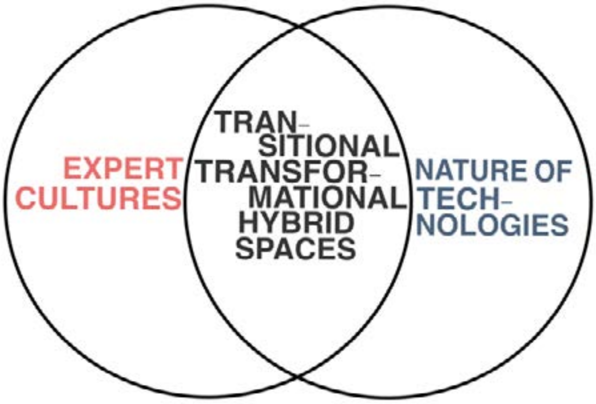

Figure 2: Techno-Anthropology (Slotina, 2021)engineering and construction industry (AEC

conventional ethnography, though the length is replaced by the intensity of data collection, writing is subsidized by recordings. Knoblauch (2005) in his explanation of focussed ethnography also mentions the familiarity with the field. This was also the case in this setting – the researchers were already familiar with the settings before data collection started. This situation can raise challenges, for example the researchers should know how to differentiate between her/his own knowledge and the common or shared knowledge (Knoblauch, 2005). Research methods like observations and semi-structured interviews helped to understand the participant's point of view and set aside former assumptions.

"An interview is literally an, and inter change of views between two conversing about a theme of mutual interest." (Kvale, 1996, p. 2)

The goal of the interviews was to get a sense of architects' perspective on digital framework - VDC and the way VDC affects their everyday lives. Semi-structured interviews are open ended qualitative data that tries to bring forth the participants' experiences, beliefs, and thoughts. They were chosen because they open to opportunity of a conversation style interview where even though certain topics are covered, still there is space for discovery and flow. The questions prepared went in depth of why and how VDC affects the architectural project development but also allowed to enquire deeper into certain subjects that raised an emotional response.

The duration of the interviews was between 30 to 50 minutes, depending on how much the participants wished to elaborate on the themes brought up. A total of seven interviews were conducted, all of them were transcribed and analysed in comparison to PPT framework. The interviews took place on Microsoft Teams to have most flexibility with time and recording possibility. Resources used in support of the interviews were Microsoft Teams recording and transcription tool, the interview guide, letter of informed consent and PPT framework.

The scope looks at architects that are already familiar with VDC and have used it in their projects. That way the interviews can be kept focused on the perspective of these architect instead of assumptions by them.

The main objectives of the interviews were (1) to voice architects' perspective on digital frameworks like VDC, (2) to find out how do architects think digital frameworks affect the way they collaborate interdisciplinary and (3) to find out how digital frameworks affect the way architects conceptualise design.

Categorisation of meaning for the interviews was done by categorisation (or grouping) their answers into following three categories: People, Process or Technology (PPT). This categorisation is based on the IDDS research roadmap (Owen, 2013). In addition to the PPT mapping, a more thorough mapping was done to see how the interviews categorise within the larger innovation imperatives research roadmap by Owen (2013). This was done in order to see which parts of the future research is most present in the architects' discussions.

To validate respondents' words triangulation can be applied, through the checking of findings from one set of data source and by collecting data from others (Hammersley and Atkinson, 2007). Triangulation is a means to strengthen what can be said from the information that is collected in research and implies that meaning is not only generated from one data source only. This study triangulated between observations, semi--structured interviews, and literature.

Ethical considerations

Ethnographic work seeking in depth knowledge from people about their practices and ideas requires also for ethical standards to be observed. This study involved vulnerable people in a way of their work positions, therefore, specific informed consent was asked for to ensure that participants are protected and have the right to withdraw from this study at any stage. The following steps were taken: the participants were fully informed in writing before commencing the investigation so to provide them with the opportunity to safeguard their identity and to inform them about their rights to participate or withdraw from this study. Assurance was given that no individual or company would be identified by name in any published materials, instead pseudonyms were used.

There are five main ethical issues to consider: informed consent, privacy, harm, exploitation, and consequences for future research (Hammersley and Atkinson, 2007). Being researched can also create stress and anxiety, especially in work environments, therefore making participant to feel relaxed and ensuring that the information will not be used in any other means as what they have agreed to is important. Participants should feel save and not exploited in any way (Hammersley and Atkinson, 2007). Having a Techno-Anthropological background and well-structured process, we believe we have addressed all the necessary steps for the participants to feel safe and not be exploited in any way.

4. FINDINGS AND DISCUSSION

This chapter will present the findings and discussion from the semi-structured interviews that was conducted between the architects familiar with the VDC framework. This study focuses on a very specific setting: a group of architects that have been or are participating in the NTNU organized course on the use of VDC framework in construction projects. All the participants have had architectural training before and are actively working as architects in an architectural practice at the or actively contributing to the further development of the architectural practices.

Once the access was gained to the NTNU course, an invitation to interviews was sent out to the architects that have participated in the course over several years. Eight interviews were conducted from which seven were decided to be used in the data collection, choosing a scope of architects that currently work in an architectural role. Table 1 shows the architects interested to participate in the study had 10-25 years' experience and had a good overview of the construction industry and the AEC project principles.

Table 1 – Participant list in the study

Pseudonym	Work experience	Main role / Comments
Anthony	~13 years	Architect with a specialisation in existing buildings / works with BIM strategy in the office
Ben	~15 years	Senior architect / an architectural project lead / an interdisciplinary project lead
Camilla	~11 years	Interdisciplinary project leader

Daniella	~12 years	Leading large architectural teams
Ethan	~20 years	Strategy development for building collaboration, quality management
Frank	~16 years	Architect with a specialisation in façade design and interdisciplinary collaboration
Grace	~25 years	Architect / design lead / specialized in visualisations and animations and user coordination

The interview data was coded using PPT framework and extended to include the innovation imperatives proposed by IDDS research roadmap (Owen, 2013). The questions during the semi-structured interviews covered all the main subjects of the research roadmap to find out the main concerns architects were interested in to discuss in detail.

The result of the coding of People, Process or Technology (PPT) is represented in the Figure 3. The result of this coding shows that although interview questions were well distributed between all the PPT areas, the main subject discussed in the interviews was technology. This confirms the importance of technology in the architectural offices. Most interview participants also mention the fact that they got exposed to the digital drawing tools either already in their education or very early in their carriers.

Figure 4 presents the result of the coding towards innovation imperatives by use of a modified research roadmap developed by Owen (2013). We have chosen to present them in a more circular manner in order to show the areas that participants were more concerned about in proportional manner. For example, "Economic realities" under "Drivers for change" was the least discussed, as well as "Greatly Reduced Litigation" under "Opportunities".

We thought this map better represents the different concerns within the architectural discipline at this point. One should take into account that all the architects interviewed are interested in the new ways of working and collaborating with other disciplines and have been

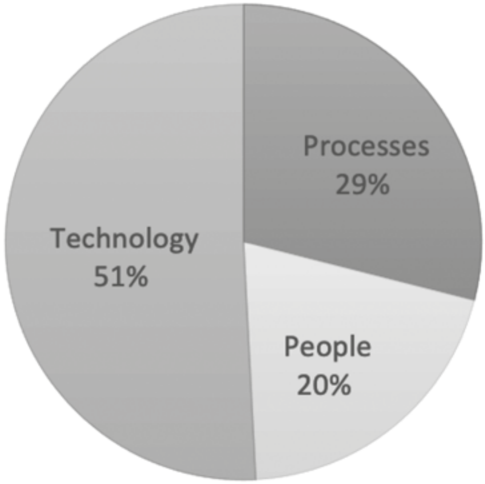

Figure 3: Interviews mapped towards PPT framework

participating in VDC course. Therefore, with no surprise, "Opportunities" subject in digitalisation was the most covered topic (distributed equally between Project and Programme Opportunities).

Grace: "Yes, yes, yes. And I am very into the digitalization. I think my first meet was like, whoa, "blow your mind"!"

Camilla: "I'm leading an interdisciplinary project group. So, I haven't been modelling as much or using the tools myself for modelling, but the tools are still very useful for me in my role - to look for collisions etc. I prepare a lot with our BIM coordinator and have all the disciplines combine all their models and we can work together in Revit. All the disciplines have their models live and can see what everyone else is doing. I find that very useful."

Second most covered topic was "Enablers"- talking about Benefits, People, Processes and Technology in the AEC industry. Architects main concern and topic of interest was "People". Although technology could be the one pushing further the AEC industry and particularly architect trade itself (Abdelhameed, 2006; Gade et al., 2019; Hermund, 2009;

Figure 4: Interviews mapped to innovation imperatives proposed by IDDS research roadmap

Owen, 2013)designers struggle at times to apply the different BIM-tools. In order to understand this disjoint, it is necessary to understand first the existing practices of different specialists in the building design process in order to improve future development and implementation of BIM. The aim of this article is to investigate the consequences of using BIM-tools in a collaborative building design setting consisting of different specialists. A case study was carried out to trace when BIM-tools were used (or not, it appears that the architects participating in this study believe that what matters more at the moment is to further develop architects' profession and take a stand within the AEC industry.

Daniella: "In the projects that I'm used to work in - the big complex projects - architects are often leaders. [..] so I don't see that changing. [..] but it's interesting to see that there are almost no architects in this VDC course, it's mostly entrepreneurs and they are like "high-fiving" each other up on stage like this is their thing. [..] I just think we (should be) a bit aware of that. To be able to position ourselves in this. If this is something the whole building sector is trying to work towards and we are supposed to lead those projects also in the future, then we need to kind of own this framework."

The suggestions for improving the architects' profession splits in two main categories - "a master builder" profession or "a fully integrated architect" with the rest of the disciplines.

For example, Anthony suggests that architecture is a language of its own and because of that it should be as a base for all design work. The thought of *language of designing* also corresponds to what Schön (1983) suggests as a basis for all design work. Anthony believes that all architects should have a great overview of all the disciplines and be in a way "master builders".

Anthony: "because it's a language… in 10 years' time, an architect student in the first year of the bachelor, I hope, really hope that he/she will start by designing by hand, and that he/she will be out in the world designing, building details, understanding how things are connected and how they are put together. Because without that knowledge you will never have a good BIM. But when you have that knowledge and you start doing BIM, then that 3D model will have a much more complex identity, because you know how things are done, you design them."

In the other category - "a fully integrated architect", Grace believes that involving all the disciplines in the early phases of the projects would create a more integrated design project and process and allow for innovations and setting the right ambition levels in the early phases of the built projects.

Grace: "Yes, because if we think about the best project ever… I think it is where everybody in the process understands the goal and we have the same goal with the project and the same ambitions, because often the architect is the one who has the most ambitions of everybody… [..] Yeah, that everybody has the same goal and the same purpose. And then to work with a good workflow, a good communication interdisciplinarity very early, so you can also find the best solution for the environment that everybody can give their input soon enough."

The third most covered topic in the semi-structured interviews was "Barriers". Participants in the interview were most concerned about "mindset barriers" and particularly the idea of a "Change as a Risk". There was only one participant that did not see change as a risk.

One of the examples of "Change as a Risk" is discussed by Ben in his interview. He believes that the new ways of working in AEC industry can bring challenges to the architectural qualities, and his belief is that these barriers cannot be overcome if architects do not get involved in the development of these new ways of working.

Ben: "Today the situation is very different. It's a client based, controlled economic system or it's a contractor. The contractors run (the project) basically by a hierarchy of the economy and time. I think it's very challenging for architects to get more (quality) on board. I think it's important that they (architects) face these challenges and challenge them (further)".

Frank said that the main risks is to know the right priorities when the project becomes complex and know what to concentrate on when.

The more data and information models have, the more complex it is to concentrate on the right part of the project.

Frank: "It is a very nice way to get more control (with BIM models), but at the same time it's also something where you can put more information. So, it is growing in complexity as well. So maybe the danger is that you're starting to lose focus on what's important. [..] Especially when you're starting to put in longevity of the products and recycling. There's a lot of things that's going to come that will add to the complexity that's already there. I mean it's a bit challenging to have the right focus".

Ethan expresses a possibility for the discipline shift similarly as Schön (1983) - over time the boundaries of architectural discipline has shifted and changed. This could happen again with the new digital framework implementations.

Ethan: "Or what kind of disciplines are going to exist in the future? What other roles? Maybe the roles are nothing like now. Maybe you don't have an architect and static engineer afterwards. Maybe you have a completely different kind of disciplines afterwards."

Although the overall coding shows that the architects participating in this research think that there should be more emphasis on the people, collaboration, and skill development. When looking into the details of the interviews, they clearly elaborate on the concern of the processes too.

The overall coding shows technology to be an important part of the everyday lives of architects, but when looking more into details of the interviews we see that the technology is the least mentioned as a concern. This shows the point that the technological development is moving forward rapidly and what architects are mostly concerned about is improved people and integrated processes at this stage of the VDC development.

5. CONCLUSIONS

The research discussed in the paper uses Techno-Anthropological methods to examine the architects' perspective on digital frameworks like VDC and how this have affected the way architectural projects are being developed. This entailed (1) further literature review, (2) field observations on VDC course at NTNU, (3) semi-structured interviews and the analysis.

The findings represented general PPT analysis which showed that main discussions during the interviews did concentrate on the technology part, but this did not seem to be the main concern when the interviews were coded in more detail. The main subjects that architects were interested to discuss were (1) "The Opportunities" with the digitalisation in the AEC industry; (2) "The Enablers" of this digitalisation – more specifically People and the role of architects in the future projects; (3) "The Barriers" that the digitalisation can bring – particularly "Change as a Risk" and would disciplines in the AEC industry shift by going through the changes it does now.

This paper highlights that architects familiar with the VDC framework are aware of the changes in the AEC industry.

The architects' perspective on the digital frameworks like VDC is that more architects should be familiar with the processes and changes in the AEC industry in order to be part of the shifting of the disciplines and roles within the AEC projects. This could either be "a master builder" type of role – having an overview of all disciplines (for example an interdisciplinary project lead role) or "a fully integrated architect" that specialises on the design processes and collaborates closely in an integrated interdisciplinary project team.

The further research work could lead to look into the perspectives of architects not yet familiar with the VDC framework or exploring the perspective on the other disciplines in the AEC industry and bring forth their perspectives of the digital frameworks like VDC.

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A PARAMETRIC APPROACH FOR UTILIZING LOCAL PLANT CAPITAL IN VERTICAL GARDENING INITIATIVES

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ABSTRACT

Amidst unprecedented events and imbalances, an ever-increasing sense of uncertainty and instability prevails, the essence of which is encapsulated with the word *permacrisis.* Concurrently, the previously underestimated severity of biodiversity loss and ecological collapse comes back into focus, ranking currently high, both in short- and long-term severity of the global risks by the World Economic Forum (2023, p. 11). According to the United Nations Sustainable Development Goals (UN-SDGs), stopping biodiversity loss is a critical component of attaining sustainable development. Having *past the point of no return*, the imperativeness of studying the numerous interactions between plants and the built environment becomes prominent. Mainstreaming Nature-based Solutions (NbS) as the cornerstone upon building resilience constitutes a promising pathway. Through creating new synergies and promoting inclusive, capacity-building processes related to climate change and environmental protection, NbS enable and *support effective and transformative learning and comprehensive understanding about possible futures* (ThinkNature, 2020, p. 189). For this project, among the range of NbS, the practice of vertical gardening is selected, as a subcategory of NbS, which has not been extensively explored and thus, is underused, especially in Greece. Within this frame, this project aims to cover this shortfall, by bringing out a parametric approach for utilizing local plant capital in vertical gardening initiatives; additionally, it can be utilized by the plethora of nature-based practices. Thus, this work focuses on the case of Greece, with a database on the work of Dimopoulos et al. (2013) *Vascular Plants of Greece An annotated checklist*, forming the basis of the methodology. Through this paper the aim is to approach quantitatively - in relation to circumstance and projects' locality, the existing NBS vegetal potential. The work constitutes an initial approximation of an ecological spatial strategy - like Biodiversity Net Gain (BNG) or the conceptually similar scheme of environmental offsetting, and reflections on this analogue will be made on the last part of the work. The procedure excels the local and can be replicated into various frameworks.

Keywords: Parametric Method, Vertical Gardening, Digitalization, Ecological Strategy

INTRODUCTION

In the present dense urban environments, living ecosystems like trees and plants bring natural life closer to humans, enhance significantly the overall space experience and constitute a key element in the combat of climate change. Taking into account the capacity of plants to deliver ecosystem services is species and contextually dependent (Fineschi & Loreto, 2020), and considering the additional stress of future climatic conditions

(Naboni, 2019), numerous sources emphasize the urgency of encouraging vegetal diversity into the built space (Antonelli et. al., 2020). Within this frame, the research project builds upon the dynamics of utilizing Nature-based Solutions (NBS) and specifically those of type 3, i.e., artificial eco-systems, such as living walls or vertical gardens (VG), (and vegetated roofs according to the typology of Eggermont et. al., 2015). Additionally, NBS place a strong emphasis on tying biodiversity preservation to climate-resilient and sustainable plans for development (Pauleit et al., 2017, p. 32) and the ThinkNature platform (2020, p. 28) emphasizes that the construction of VG and green roofs cannot be regarded as a NBS, if factors like biodiversity and sustainability are disregarded. Based on these literary observations, this paper attempts to approach a controversial aspect of the practice of VG which has to do with ecological performance and more specifically with the plant selection criteria.

LITERATURE REVIEW

Back in the 1980s, Patrick Blanc pioneered the use of VG by re-inventing them as a building greening technique (with the support of a continuous system). Today, highly specialized nature-based initiatives that provide the design, installation and maintenance of VG make them widely available, either as continuous, or as modular systems. Their exquisite aesthetic value, which constitutes the primary source of demand, along with the common perception of the 'green virtue', contributed decisively to their rapid popularity. As multidimensional and multifunctional artificial niches, VG are used to accomplish particular technical needs and functions related to modern building architecture. However, VG, permanently attached on the vertical plane, have to cope with a plethora of altering conditions. Achieving these unfolding processes constitutes a dare and thus, specialized design abilities as well as ecological understanding are required (Van Zuilekom, 2021). As a consequence, there is a demand to wisely employ plants, not merely as objects to be admired for their aesthetic attributes.

Taking these into account, utilizing high species diversity outreaches plainly design decisions or aesthetic statements, and provisions towards VGs' persistence in pathogens, location responsiveness and an overall environmental contribution, which can be condensed as resiliency (Roe, Seddon and Elliot, 2019, p. 4; Blanc 2020; Van Zuilekom, 2021). To this direction, expert guides, policy reports and the relevant international literature advocate towards an insistent need for the green building sector to shift towards impact-based dialectics and applications, urging the imperative for ecological performance metrics, and evaluation of the benefits of VG initiatives, so that the driver of demand becomes biodiversity contribution and the aesthetics, tie up as a corollary (E.C., 2022, p. 44).

Thus, this project builds upon the prospect that VG projects in the future will comply with more appropriate plant selections, which are more in tune with the local environment (Girot, 2020, p.74), while concurrently encouraging ecological leveraging of domestic – in particular Greek, plant species. Motivated by the dictum *'if you can't measure it, you can't improve it'*, an attempt is made to bring out a procedure that approaches quantitatively - in relation to circumstance, the existing VG vegetal potential in relation to each projects' locality. The aim of the process is to establish communication channels and spark convergence between interdisciplinary fields – planning and architecture, ecology and conservation, in order to establish a common ground for the adoption of climate-smart, well-informed and biodiversity-driven decisions.

Practicable gains of this process are appointed especially when considering smart city paradigms, which by means of digitization, foster the discussion and accommodate the framework for innovative and inclusive procedures for climate change mitigation – like digital collaborative platforms (Geropanta et al. 2022). Furthermore, it would be interesting to consider the possible integration and exploration of such ecological processes in cross-over studies in virtual reality (VR), which are looking into the psychological and physiological effects of green walls on people (Yeom, Kim and Hong, 2021). Within this context, another point that in the author's opinion is eminent and needs to be further explored, is the prospect of digitally combining and unifying/integrating at the regional level floristic catalogs or checklists with Red List Assessments (RED DATA BOOK, 2009) – where available, of rare and endangered plants or other sources of relevant geospatial data.

A PARAMETRIC APPROACH AS A FEASIBLE PATH OF ECOLOGICAL LEVERAGING IN THE BUILT ENVIRONMENT

The present work focuses on the case of Greece, with the database on the work of Dimopoulos et al. (2013) *Vascular Plants of Greece An annotated checklist*, along with its *Supplement* (Dimopoulos et al. (2016) forming the basis of the methodology. Dimopoulos et.al. (2013), underline that comprehending the wealth of the species in a specific area is essential for any conservation and sustainable use of plant diversity efforts. *Vascular plants of Greece: An annotated checklist* is a collaborative effort that assembles the entire floristic asset of the Greek region. It integrates a multitude of information on nomenclature, endemism, distribution, chorology, life form, and so forth. As an important inventory of Greece's plant history, it aids in the protection and responsible exploitation of the rich Greek flora, while also serves as a foundation for a variety of botanical, ecological or, as in the present case, interdisciplinarity research investigations. The primary goal of synthesizing *Vascular plants of Greece: An annotated checklist* was to transform the previously dispersed or incomplete

Greek vascular flora into a complete, detailed, and up-to-date Checklist, while concurrently encouraging further research and collaboration on the knowledge, understanding, and thus conservation of Greece's angiosperms, gymnosperms, and pteridophytes, as well as other taxa, that may be or become threatened or endangered in the future as a result of habitat loss and land exploitation.

According to Dimopoulos et al. (2016), the total number of records in the Checklist is 7739, with 5758 species and 1970 subspecies representing 6620 taxa belonging to 1073 genera and 185 families. In concise, the list incorporates regional distribution, status of the taxa (native, alien and range restricted), as well as chorological categorization, life form categorization and habitat categorization. Regarding the Checklist and its annotations, the 13 floristic regions or phytogeographical regions of Greece are used to code regional distribution data, with plainly visible and distinguished borders between regions. The regions listed are: IoI - Ionian Islands, NPi - Northern Pindos, SPi – Southern Pindos, Pe - Peloponnisos, StE - Sterea Ellas, EC - East Central, NC - North Central, NE – Northern East, NAe - North Aegean Islands, WAe - West Aegean Islands, Kik - Kiklades, KK - Kriti and Karpathos, EAe - East Aegen Islands. An alphabetical sequence of families, genera, species, and subspecies has been followed within the primary classification groupings, followed by the category of their status, with regard to native, alien and range restricted taxa. Then on, a distinction is made between the 21 chorological categories. A taxon's chorological category is defined by its present area of native distribution and refers to a collection of taxa with broadly congruent distributions. The chorological categories listed are: Bk – Balkan, BI – Balkan-Italian, BC – Balkan-C European, BA – Balkan-Anatolian, EM – E Mediterranean, Me – Mediterranean, MA – Mediterranean-Atlantic, ME – Mediterranean-European, MS – Mediterranean-SW Asian, Eu – European, EA – European-SW Asian, ES – Euro-Siberian, Pt – Paleotemperate, Ct – Circumtemperate, IT – Irano-Turanian, SS – Saharo-Sindian, ST – Subtropical-Tropical, Bo – (Circum-)Boreal, AA – Arctic-Alpine, Co – Cosmopolitan. Additionally, the chorological dissection embeds two more categories: the first is in the form [], referring the origin of alien taxa: [trop., subtrop., neotrop., paleotrop., N-Am., S-Am., Europ., Pontic, Caucas., Arab., Arab. NE-Afr., S-Afr., E-As., SE-As., Austral., unknown]. The last chorological category emphasizes the presence or absence of Greek endemics, i.e., taxa with restricted distribution in the Greek territory. Next comes the separation regarding life-form types: P – Phanerophytes, C – Chamaephytes, H – Hemicryptophytes, G – Geophytes (Cryptophytes), T – Therophytes, and A – Aquatics. The last categorization is about habitat categories separated into eight categories: A – Freshwater habitats, C – Cliffs, rocks, walls, etc., G – Grasslands, H – High-mountain vegetation, M – Coastal habitats, P – Xeric Mediterranean Phrygana, R – Agricultural and Ruderal habitats, W – Woodlands and scrub. Within habitat categories, when a listed taxon applies for more than one category, more abbreviations are given accordingly. For additional information and further clarification on the descriptions about the categorizations, descriptions and additional information, one could refer to the original articles.

In today's literature the list described above can be found in a pdf format. Due to the high importance of the list, it would be beneficial for future research purposes to be open access and cross-functional for data handling, so that it can promote two-way sync future investigation and extend its use to interdisciplinary fields of research. In this way, the list, as a set of interrelated categorization criteria, could be considered as a parametric tool *per se*. Depicting this claim, if one takes the hypothetical case of a project in Crete (applying regional distribution), from the total 7739 plants of the Greek flora, she/he emerges with 2079 plants (Dimopoulos et al., 2016, p. 304). If one applies accordingly all the additional categorizations i.e., status, chorological categorization, life form categorization and habitat categorization, is given out an exact approximation of the local plant capital suitable for utilization. Thus, emerging with a tangible number establishes the basis upon which collaboration activities as well as protection and conservation practices can be promoted.

INTERRELATIONS

Switching back to the VG scheme, plant selection criteria serve the intended language of structure and design. Determinant factors in natural plant species selection in VG are their height, direction of plants' development, irrigation needs and ease of maintenance (Kahraman and Gür, 2022, p.236), while the selection plan should potentially encompass vegetal factors like: hardiness and heat zone, height-spread-width, wind resistance, planting distance, growth rate, whether the plant material environmentally degrades the area, etc. Digital tools constitute an indispensable part for environmentally-informed design processes. Thus, a sites' locale aspect and position via a Direct Sun Hours (Ladybug Tools), can be utilized for a correspondence regarding plants sun requirements (full-sun, semi-shade, shade) and juxtaposition (Figure 1).

Another standpoint about the feasible extensions of the practice emerges with the perspective of digitally unifying regional floristic catalogs with Red List Assessments of rare and endangered plants, pointing to protection and conservation measures. Taking as an example the vulnerable (VU) Greek endemic *Alyssum lassiticum,* Turland (2009, pp.78 - 80) points out the actions and the requirements under which *ex situ* subpopulations could be propagated and distributed so that will further allow the reintroduction of the species or the experimental enhancement of natural subpopulations in case of decline within the natural population. Thus, the viability for the VG sector in assisting and supporting biodiversity widens. Currently, this prospect is gaining acknowledgement, while

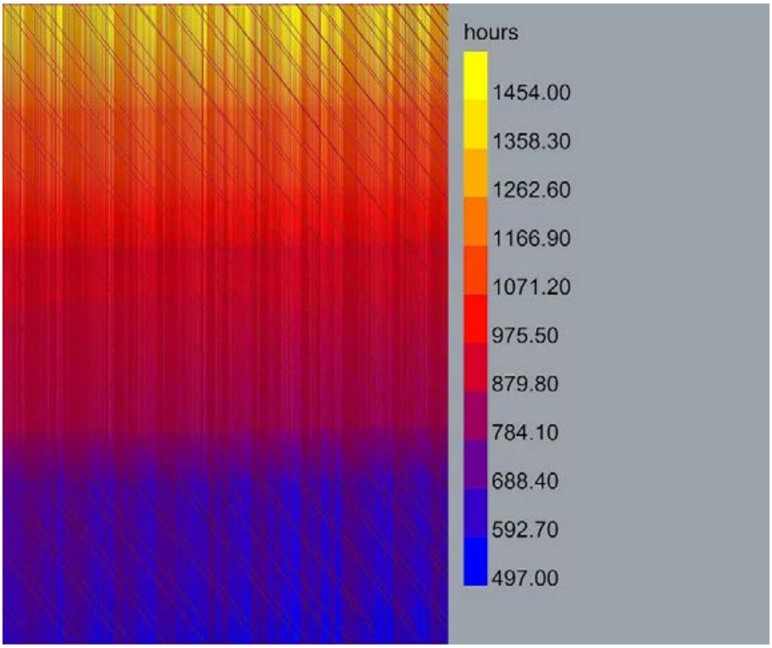

Figure 1: Annum Direct Sun Hours for a building's 22m. façade in Athens, Greece. Orientation: NE

countries like the United States, United Kingdom and Australia, have given the necessary attention towards this direction, by establishing laws, policies and strategies before, during and after development for balancing the not so seemingly interrelated, economic growth and ecological protection.

Biodiversity offsets are quantifiable conservation benefits that occur from measures aimed at compensating large residual biodiversity loss from development projects (OECD, 2016), which thus become development challenges (Roe, Seddon and Elliot, 2019). They are intended to be adopted only after reasonable actions to avoid and minimize biodiversity loss at a development site. Although few programs have embraced a more ambitious goal of net gain, the most common goal adopted in offset programs is no net loss. Such actions include accounting devices integrated into a process to construct a calculable space in order to answer concerns about calculating net biodiversity loss or gain (Cuckston, 2019). The three types of biodiversity offsets are: one-off offsets, which are commonly utilized in voluntary offsets and in regulatory vegetation management programs; in-lieu fees, from government representatives that prescribe a charge a developer must pay to a third party in order to compensate for lingering negative biodiversity impacts; and biobanking. A biobank is a repository of existing offset credits, with each credit representing a quantifiable gain in biodiversity as a result of measures to restore, establish, improve, or maintain biodiversity. As far as the projected negative impacts have been assessed, the developer can directly purchase offsets from a public or private biobank (OECD, 2016).

Biodiversity Net Gain (BNG), as a conceptually similar concept, succeeded Biodiversity offsetting amid international calls to improve the functioning of infrastructure systems in order to meet ecological and climate problems, with the potential of additionally becoming a valuable example for other countries (Ermgassen et al., 2021, p. 7). However, there are concerns regarding the perceived development pressures on reaching BNG. According to (Cuckston, 2019, p. 2) a basic problem is how accounting may foster conditions favorable to biodiversity-conservation and sustainable practices. Within this problematic, there are indications that point to the prospect of BNG actions being utilized within VG initiatives which, by incorporating on-site installations, provide an effective means to balance projects and even achieve BNG without the need for off-site investments – like additional land or habitat banks (ANS Global, 2021). Being a new dynamic approach, it has gained popularity among architects, builders and environmentalists (ANS Global, 2021), while the implications of such a strategy should be further explored in various contexts.

CONCLUSIONS

The presented research reflects on the practice of vertical gardening (VG), a subcategory of Nature-based Solutions (NbS), which has not yet gained popularity, especially in Greece. A parametric approach for utilizing local plant capital in VG initiatives, which could also be utilized in a plethora of nature-based practices, was pointed out, based on the work of Dimopoulos et al. (2013, 2016) *Vascular Plants of Greece An annotated checklist.* The significance of such an approach is manifold: firstly, as an initial approximation of an ecological spatial strategy that also integrates conservation potential; secondly as a convergence attempt between interdisciplinary fields; thirdly, as an incentive in fostering utilization of both VG and NbS in general and thus, promoting well-informed and biodiversity-driven, green interventions. Regarding the practice of VG, some important aspects of planning are highlighted. Finally, some thoughts on the biodiversity offsetting scheme are elaborated, indicating potential future perspectives.

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EXTENDED REALITY AS A PARTICIPATORY METHOD TO FACILITATE SUSTAINABLE URBAN REGENERATION STRATEGIES FOR BROWNFIELDS IN SOUTH INDIAN CITIES.

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ABSTRACT:

Brownfield is a multi-disciplinary concept that refers to various types of environments. The sudden urbanization and expansion of south Indian cities have led to a drastic increase in the number of brownfields it houses. Although there is no official definition, an emerging consensus has risen around the urban character of brownfields and the need for new interventions. Their location within metropolitan areas represents a strategic opportunity to regenerate the urban fabric at the neighbourhood scale. However, most importantly, architects, planners and stakeholders find it challenging to engage and communicate concepts with general users due to the magnitude of these brownfield areas. Public participation in urban planning processes is affected by what is known as the *"paradox of participation"* : in early planning phases, when there is still sufficient room for decision-making, only a small number of the people participate, while in advanced phases, when decisions can usually only be revised at great expense, a high level of public participation can be observed. The resulting delayed and more costly planning processes could be partially prevented by shifting public participation activities to a much early phase of planning processes. The reasons for the public's low level of participation in early planning phases are seen as the lack of clarity and the absence of concern due to a high level of abstraction in the concept stage. Public participation and engagement in architecture have reached a new level as expectations among the general public have increased and technological advancements are creating new opportunities. The emergence of extended reality tools offers architects and planners significantly new methods to communicate effectively with stakeholders, users and other professionals in the field. Technological experiences have reshaped how ideas are presented and continue to offer development collaboration opportunities. This ongoing research assesses the performance of extended reality (Virtual Reality and Augmented Reality) applications when used as a public participation tool and their effectiveness in communicating development ideas and strategies for the sustainable regeneration of brownfields in and around metropolitan cities in South India.

Key words: Brownfields, Virtual reality, Augmented reality, Land Regeneration, Sustainability, Metropolitan cities, Public participation.

1. INTRODUCTION

1.1 Urban and Metropolitan Brownfields

Initially confined to urban planning specialists, urban brownfields are frequently discussed within politics, the media, and professional associations. However, brownfields encompass a whole range of diverse spaces. In order to provide a satisfactory meaning, it is worthwhile not only to define the coverage of the notion of brownfields but also to clarify the characteristics of their localization, which formally determines its belonging to urban and, more broadly, metropolitan areas.

The localization of brownfields can be very heterogeneous. However, as the title suggests, this paper focuses more specifically on brownfields located within metropolitan areas in Southern India, often referred to as urban brownfields, if not metropolitan brownfields.

Broadly speaking, we can define urban or metropolitan areas as territories with a relatively high density of population and a continuously built fabric. They can be characterized by a two-fold dynamic: the extension of suburban and peri-urban areas, which tends to merge the principal agglomerations and the concentration of activities within urban polarities. At this stage, it seems necessary to underline that although metropolitan processes exist throughout India (and throughout the world), they remain very specific to each region and continent. Therefore, as is the case for the notion of brownfield, there is no precise, single definition of what urban area is considered a brownfield; it is highly context-driven.

This being said, it should be clarified that urban densification strategies developed within the compact and polycentric city perspective are clearly not limited to city centres (Emmanuel Rey et al., 2021). Therefore, this paper is based on a large number of brownfields located within surrounding suburban rings and peri-urban areas, representing strategic opportunities for the sustainability transition of metropolitan territories as a whole. The commonly accepted wording urban brownfield is therefore adopted for this work.

1.2 The scenario in South India

India, with its rich resource potential, many industries were established during 1850-1900. The introduction of railways by the British for conveying cargo catalyzed the rate of development of such industrial and colonial settlements. Many Railway Towns were established. The increment rate of in-migrants into such towns for decades resulted in high densities, congestions, unhygienic conditions, lack of services etc., thus resulting in urban blight. "Being a developing nation, can India afford to abandon huge parcels of potential brownfields?"- The debate during the early decades after independence provocatively triggered the advocacy in redevelopment codes and regulations. The government of India started formulating and implementing urban renewal and urban revitalization strategies for the sophistication and up-gradation of social and physical infrastructure by then, which could meet the demands in the near future. Bengaluru, Chennai, and Hyderabad governments took early redevelopment initiatives and could set standing examples in India. Many other municipalities started renewal programs (Govind Gopakumar, 2015). In 2005 Remarkable step was taken for urban renewal in India by Jawaharlal Nehru National Urban Renewal Mission (JNNURM) with the motto of integrated development; it worked on objectives such as the provision of essential services to the urban poor also to ensure the security of tenure at affordable prices, the sophistication of physical infrastructure, sanitation. The Mission also intended to provide proper education, health and social security for the urban poor (R Patnayaka, 2018). However, all the redevelopment strategies in both large-scale and small-scale projects in South India were formulated and implemented under the framework of prevailing urban planning norms and guidelines. With a prime focus on addressing various issues such as land use and the up gradation of the social and physical infrastructure to meet the future requirement, there is still very minimal focus on a scientific and technological approach in dealing with brownfield sites in and around growing cities.

1.3 Regenerating Urban Brownfields

While urban brownfields' potential for the sustainable transition of metropolitan areas has been demonstrated notably as a densification strategy, it should be noted that their redevelopment is far from a spontaneous process (E Rey et al., 2021). In the real world, brownfield regeneration projects encounter a series of issues, particularly related to the complexity of such operations. Indeed, brownfield regeneration projects are far more complex than constructing an isolated building or developing a new neighbourhood on a vacant plot. Related to the very nature of urban brownfield sites covering an intermediate scale—the neighbourhood—with a building legacy of variable quality, often disconnected from their context, sometimes contaminated, and suffering from a poor image, regeneration project issues are identified according to four distinct types: *sociocultural barriers, governance involved by the multiplication of actors, legal and regulatory constraints, and deterrent costs* (E Rey et al., 2021). In turn, these issues contribute to complexify brownfield regeneration projects. The proposed classification of issues needs to be balanced by a certain degree of flexibility in terms of permeability between the different types of issues since the legal, economic, or social dimensions are sometimes combined within a single resistance factor.

Although districts, cities and regions face individual challenges, planners increasingly share a common understanding of planning and its methodological approach. In detail, challenges such as climate change, demographic shifts and economic transformations have led to the perception that sustainable and resilient city design requires an integrated and cooperative planning approach for brownfield regeneration. This refers not only to the coordination of different administrative bodies but also to the inclusion of the general public in planning processes (BMUB, 2007).

2. PUBLIC PARTICIPATION

Government of the people, by the people, for the people (Lincoln, 1863) – the famous phrase by the father of modern democracy put people in the decision-making process. Likewise, in architecture, it is an essential mission to understand and reflect human needs in space formation. Higher community awareness, better access to information, readily available technology-based solutions, and expansion of the internet stimulate community involvement in the processes of architectural design, urban design and landscape architecture. The public participation process ranges from high to low levels, from simple informing to multidimensional and resource-consuming citizen control, described as the "ladder of citizen participation" (Arnstein, 1969).

The basis of the involvement of the public is two sets of participatory instruments. On the one hand, there are the so-called formal participatory instruments. This set comprises instruments being mandatory in planning processes. An example of a formal participatory instrument is that draft plans must be laid out for public inspection. In the set of formal participatory instruments, not only the intensity and the timing of the participation are regulated, but also the groups of stakeholders, such as administrative bodies, public utility providers and certain groups of citizens having to be involved in the planning process (Wolf et al., 2020; Lück & Nyga, 2018; Nanz & Fritsche, 2012).

On the other hand, are the so-called informal participatory instruments. This term refers to instruments not required by legislation but optionally available to strengthen public participation in planning processes. Informal participatory instruments focus on conversational and deliberative opinion and decision-making approaches. For this purpose, the set offers a wide range of instruments, such as Open Space or Planning Cells (Wolf et al., 2020; Nanz & Fritsche, 2012; Selle, 2013). In normative planning processes, the formal instruments are supported by informal instruments to increase the level of satisfaction of all stakeholder groups involved in planning processes. However, the current participatory framework appears as not sufficient. Surveys have revealed that more than 60% of citizens in Indian cities demand more opportunities to participate in the planning of infrastructures (Sharma *et al.*, 2022).

3. TECHNOLOGY AS A TOOL FOR PUBLIC PARTICIPATION

Inclusive participatory instruments are required to address the challenge of public participation and prevent the formation of planning conflict. Hirschner (2017) states that participatory planning needs to be strengthened by applying innovative informal instruments to identify better and accept all stakeholder groups. Informal planning instruments should focus on deliberative methods and the public's involvement in the planning process's early phases.

For architects, extended reality (XR) solutions, if applied wisely, can facilitate participatory advancement in architecture and become an effective tool. In this paper, XR is used as an umbrella term encapsulating augmented reality (AR), virtual reality (VR), mixed reality (MR) and all real and virtual combined environments. *AR is defined as a real-world environment digitally augmented or enhanced, VR is a simulation and replacement of a real-world, MR combines both AR and VR, and gamification is a way of interacting with the public and other stakeholders* (Misius, 2021).

Nowadays, different scale projects on architectural design, urban design and landscape regeneration should meet various legal regulations and formal requirements aiming to inform and involve the community. Cities take up society-sensitive projects such as refurbishing existing squares, plazas and other open spaces or even more complicated processes of brownfield regeneration, removing the existing monuments or constructing new ones (Seam et al., 2018). These areas might have controversies in their historical appreciation, recognition, or identity issues, which divide people based on their opinions and create resistance to the planned changes. However, with the leap forward of technology in XR and gamification, it became easier to inform people about the coming changes, obtain their opinions early enough and monitor these processes in different decision-making stages. If applied smartly, XR and other solutions allow "climbing up" the participation ladder to turn the participation costs into benefits for tremendous project success.

In 2020, COVID-19 pandemic hit the world, and because of the global lockdown, people became more engaged in online remote work and communication. This opened new possibilities for internet-based public participation procedures of projects under development, and many cities started using this remote, nevertheless sometimes even more efficient tool. Expecting a better outcome, modern communities actively claim the better opportunity to engage in the different kinds of city development projects at early stages. This is where VR, AR, MR, and gamification can

show its potential – instantly connect developers, authorities, planners, designers and communities together at an unprecedented pace to achieve the most appreciated and trustworthy outcome.

4.FEATURES OF EXTENDED REALITY (XR)

XR media offer features qualifying them specifically for utilization in planning processes. Viewing XR as a learning medium should highlight several of these advantageous features. Participatory planning processes may also be regarded as learning processes, for example, social learning or situational learning, as is widely discussed (Beckett & Shaffer, 2005; Hurlbert & Gupta, 2015; Reed et al., 2018; Webler, Kastenholz, & Renn, 1995). It is even worth discussing to what extent learning is the actual goal of participatory planning processes. Zender, Knoth, Fischer, & Lucke (2019) have analyzed the characteristics of several VR-based learning scenarios and explicitly named the eight following features of VR-supporting learning. While VR is a specialization of XR, we consider this list to be representative, although not complete, for XR (Wolf, Söbke and Wehking, 2020b).

Features of VR according to Zender et al. (2019) and possible benefits for VR-supported planning processes -

- *Freedom of Design:* Allows VR media to be used in any planning scenario and, in particular, to create more variants than conventional planning processes.
- *Adaptivity:* Individual planning variants can be easily created by using parameters. Specific details of planning variants can also be investigated by changing the focus of the VR scenario.
- *Sensor-motor Manipulation:* It is not a feature commonly encountered in planning processes. However, it can be helpful to validate the handling of objects or the spatial interactions with objects, for example, if a door can be opened easily or if a staircase offers sufficient space for a two-person passage.

- *Reproducibility:* Ensures that a variant can be validated repeatedly, for example, to increase the decision-making reliability of a citizen participating in the planning process.
- *Standardization:* Allows adopting defined solutions from other contexts, for example, utilizing a component library and testing them as variants.
- *Presence:* Ensures attention is mainly focused on the variants being evaluated or the solution being designed. Collaborative scenarios may also support interaction between citizens.
- *Privacy:* If necessary, the planning variants may also be evaluated without impairing the public and – vice versa – the public not being aware of the evaluation.
- *Reduction of Risks and Costs:* VR scenarios lower costs compared to real scenarios and render the creation of physical models largely redundant. The dangers of actual on-site inspections are also reduced, for example, in road traffic or during inspections of facilities being planned, such as wastewater treatment plants.

5. APPLICATION OF EXTENDED REALITY IN URBAN REGENERATION AND PARTICIPATORY ACTIVITIES

Urban planning seeks to create consensus among different disciplines and stakeholder groups, as the types, motives and scales of projects vary. Therefore, participatory urban planning processes and their following decision-making processes are challenging procedures that can cause projects to be delayed and lead to additional costs if aspects are overlooked or ignored at the beginning of planning. Although XR became an object to different fields in past years, it has barely been used in urban planning on a regular base. However, applications mainly developed as part of research projects present a broad scope of application contexts.

Following is a selection of XR applications used in different phases of planning processes.

5.1 Communicating Plans

Two-dimensional maps are an instrument established in urban planning. For example, development plans are visualised using 2D maps. Development plans define rules that construction projects must adhere to as a prerequisite for building licenses. It reaches from the physical dimensions of potential structures to methods of construction. Non-professional planners may find this amount of information and the high degree of abstraction challenging to understand. Broschart and Zeile (2015) introduced the augmented development plan to address this challenge. By holding a mobile device over marked development plans, users can choose between different information layers according to their individual interests and relevance. Further, three-dimensional counterparts translate abstract information into visual dimensions.

5.2 Finding Designs for Public Spaces

Public spaces are fundamental assets of urban areas. As streets, squares and parks, these public spaces are indispensable for the quality of life in particularly densely populated cities. As part of the Right of the City for all citizens (Holm & Gebhardt,2011), critical factors such as uses and activity, comfort and image, access and linkages, as well as sociability determine the quality of life (PPS, 2019). Thus, the design of public spaces is an essential aspect of urban planning. In this context, aiming at enhancing the design processes of public spaces and as part of a research project, the Mixed Reality Tent (MR-tent) was established. The MR-tent targets to foster dialogues among urban planners, architects and citizens regarding ideas addressing urban challenges. Technically, the MR-Tent consists of various components, such as a table as a tangible user interface enabling users to make changes to urban plans based on a digitalised geographical map. A video projection depicts the proposals three-dimensionally. The projected urban plans can be directly modified through an additional instrument named Urban Sketcher (Maquil, Psik, Wagner, & Wagner, 2007).

5.3 Conceptualising the Build Environment

Decision-making in urban development requires comprehensive and analytical approaches, specifically for planning buildings, since buildings strongly impact perception and quality of life in the buildings' near environments.

While in the past decades, the impacts of proposed buildings were analysed through physical models making changes challenging to adopt, XR applications offer new options. The XR application Arthur (Broll et al. 2004) supports users in finding locations for new buildings using augmented scenarios of the city of London. Users can modify different parameters, such as the dimensions of the proposed building as well as existing structures. Different dynamics, such as the pedestrian flow, can be simulated to understand the impacts. Focusing on "rule-based emergent planning supported through mobile reality and gamification", Imottesjo and Kain (2018) developed the MR application Urban CoBuilder. Urban CoBuilder enables users to "design urban environment on-site". Further, Urban CoBuilder allows crowd-sourcing data; thus, collective results of individual design and planning decisions can be gathered.

5.4 Defining Architectural Design

In addition to the physical dimensions of buildings, the buildings' aesthetical appearance strongly impacts the perceived quality of the environment (McIntyre, 2006). Thus, the decision-making process of the design should involve not only planners and architects but other stakeholder groups as well. To improve the communication between stakeholder groups in the design process, Allen et al. (2011) propose a smart-phone prototype system as an AR architecture instrument. The proposed system focuses on visualising proposed 3D architectural designs on existing buildings. Through an interface, users can provide their degree of approval on the design (Allen et al., 2011). While this instrument can be solely applied to existing structures, Carozza, Tingdahl, Bosché, and van Gool (2012) present a monocular vision-based augmented reality approach "in which the urban environment is augmented with virtual static and dynamic objects, such as buildings and people". Thus, from the pedestrian's view, proposed constructions can be visualised in their environment.

5.5 Visualizing and Experiencing Invisible Factors

Besides visual elements, invisible aspects like noise, environmental pollution or heat are important facets that need to be considered for urban developments. XR can instrument the understanding and communication correlations between urban patterns and invisible aspects. The use of VR for multisensory environmental evaluation can be understood as "one of the innovations in the planning process to support the involvement of the local population in shaping their living environment"(Jiang, Maffei, & Masullo, 2016).

To address the issue of communicating invisible aspects in planning processes, the Singapore-ETH Centre for Global Environmental

Sustainability (SEC) launched the screen-based application CityHeat. CityHeat visualizes the correlation between traffic heat emissions and urban heat based on cellular automata-based data. Users can move through the virtual city while the heat is visualized on a micro scale from blue (min.) to red (max.) (Cristie, Berger, Bus, Kumar, & Klein, 2015). Focusing on redevelopments (Jiang et al. 2016) created a VR application for e-participation in urban sound planning. The core is audio-visual scenarios of urban places, in which users were asked to move to different positions and to evaluate the quality of their virtual stay based on invisible effects such as the sound environment (Jiang et al. 2016).

6. CONCLUSION

The presented XR applications in the context of urban planning show a wide range of applications with various conceptual approaches and objectives. In urban planning, the participation of all relevant stakeholder groups is crucial. However, the current implementation of participatory planning processes is deemed improvable. Extended reality (XR) media represent a promising approach to improving participatory planning processes. The maturity level for MR hardware and software has advanced considerably in recent years. In this paper, various examples of XR-based applications in planning processes have been presented. The advantages of XR applications in planning processes identified are - improvements in comprehensibility, improvement of the planning process itself, support of interactivity, also for collaborative scenarios, and increased traceability of the planning process. In particular, comprehensibility, interactivity and accessibility of the XR-based instruments are considered relevant to shift public planning activities to earlier phases of the planning process and thus to counteract the paradox of participation. Future work should contribute to systematically developing usages of XR applications in urban regeneration strategies for brownfields in and around South Indian cities. Eventually, future work should structure XR media in urban brownfield regeneration according to characteristics supported, such as application contexts, planning objectives and modes of collaboration. Further, it is required to analyze planning processes concerning phases supportable by XR media and, in particular, to examine to what extent the use of XR media will change the planning process involved in brownfield regeneration.

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SIMULATION OF HUMAN BEHAVIOR AS AN AUXILIARY DESIGN TOOL

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ABSTRACT:

This review paper summarises the current state of digital simulation methods used to analyse human behaviour in physical environments. It aims to identify why digital simulations of human behaviour are not yet commonly used by architects and urban planners and to provide a systematic review of available methods, software tools, their capabilities and limitations. It covers physical models, Space Syntax, virtual reality and dynamic simulation methods for pedestrian and occupant models. There are a number of most common decision-making processes for pedestrian and occupant models. Rule-based process involves predetermined rules or heuristics. Markov Chain uses probabilities and the current state to determine state transition. Goal Oriented Action Planning chains predefined activities to achieve a specified goal. In Narrative-based modelling a narrative governs agent behaviour. In Game-theoretic approach interactions are modelled as a game. Reinforcement Learning involves learning through rewards or punishments and Artificial Neural Networks learn from data and make predictions based on that learning. Although Artificial Neural Networks come with many benefits, such as high flexibility and the ability to handle uncertain and incomplete data, it is a relatively new field of research and it requires significant computational resources. Each process has its own strengths and limitations. Multiple algorithms or decision-making processes can be combined to achieve the desired simulation properties. There are multiple digital simulation software tools for pedestrian and occupant simulations. Some of them, such as SUMO, Aimsun, and MATSim, are optimised for transportation simulations but are not suitable to become auxiliary tools in the architectural design process. PathFinder is a software for simulating evacuation scenarios. Anylogic is a flexible user-friendly tool suitable for a wider range of applications. Tools like IES and CitySim are used for building performance optimisation. A game engine Unity is a suitable option for creating interactive and visually appealing models, however it requires programming knowledge. A simulation in a 3D environment is more complex and requires more computational resources, but it can bring more realistic results compared to simulations in 2D. The paper concludes with discussion about the reasons why digital simulation has yet not become a common tool in architectural practice.

Keywords: simulation of human behaviour, digital simulation methods, agent-based model, pedestrian model, occupant model, decision-making process

1. INTRODUCTION

Human behaviour in the physical environment is very complex and depends on numerous factors. It is the research subject in several scientific disciplines, while each of them explores a specific aspect and its impact on the resulting behaviour. The relationship between the environment and human behaviour is an important factor of the architectural and urban design process. However, it can be difficult to predict it accurately, especially in an environment not yet built. A design proposal is therefore only based on the assumption of the architect or urban planner based on his knowledge and previous experience.

Information about how people actually use the space can be captured and evaluated in a post occupancy evaluation process, which can be processed for a building as well as public space. It helps us understand how people behave in space and generally valid behavioural patterns can be derived. An example can be the generally accepted fact that human activity of a reasonable capacity in a public space attracts other people to perform activities in the same place. However, knowledge of general behavioural patterns does not yet allow us to fully explore and test human activities in a specific proposed space before it is physically built.

One of the approaches to comprehend complex spatial behaviour of people including all interactions of individuals with each other and with the environment in a given space is the use of a digital simulation. A simulation model can be developed based on observed behavioural patterns in specific types of environments. Moreover, contemporary possibilities of artificial intelligence, such as machine learning, enable such model development directly from real-world data. In the field of architecture, digital simulation is a potential tool for pre-occupancy evaluation. Problematic parts of the design might be identified and redesigned before-built. Architects might be able to verify the impact of the proposed space on future occupants in many variants throughout the whole design process and in this way the simulation might help to improve the overall quality of the final architectural proposal.

2. MOTIVATION AND GOAL

Despite the fact that contemporary technologies bring multiple possibilities for creating simulation models of people and their behaviour and are increasingly utilised in other industries, they are not being used in common architectural practices. Exceptions are some models that were created only to verify the designs of large buildings with a high budget or models for research purposes. To identify reasons why digital simulations of human behaviour are not yet commonly used by architects or urban planners, it is necessary to analyse and review the existing possibilities of digital simulation regarding human behaviour. The goal of this conference paper is therefore to summarise the existing research and bring a systematic review of available methods, existing software tools, their properties, capabilities and limitations. The review will be followed by a discussion, how digital simulation methods might become better available for broader use in architectural practice.

3. HUMAN BEHAVIOUR SIMULATION METHODS

3.1. Physical models

In the pre-digital era, the traditional practice for analysing the relationship between a proposed building and its future users was to create a physical model at full scale. Real people could then test mostly ergonomic aspects of the space. For obvious reasons, such models could only be built and evaluated in a limited size, it was therefore not possible to analyse entire buildings or urban units, but only small fragments of buildings.

3.2. Space Syntax

As technology has evolved, new possibilities for simulation have been developed. Space syntax is a theory and methodology that can be used to analyse the relationships between the morphology of space and human behaviour. Based on the modelled space and spatial relationships, a set of analytical tools identifies whether and how these relationships influence the social activities of people in a given space (Hillier, 2007). The basic tool is a graphical representation, where aspects of space are represented by nodes and their relationships by line segments that connect them. Social activities are then calculated as functions of these spatial characteristics. Using Space syntax, it is possible to predict the impact of urban changes or interior layouts on social activities. It is a static deterministic model where spatial behaviour is modelled as a direct result of the morphology of the space and does not include dynamic aspects such as interpersonal interactions, temporality or attractors in the environment.

3.3. Virtual reality

The spatial limitations of building physical models are overcomed by virtual reality technology, where several users can simultaneously enter a virtual building or space and test the effect of space on their movements and activities. However, for technical reasons, the number of people who can be in a given space at the same time is currently limited to approximately 5 users. The quality of the experience in virtual reality is not optimal, and users may be distracted by the absence of tactile sensations, insufficient image quality, unconvincing graphic appearance of spaces, headaches or feelings of nausea. Nevertheless, contemporary headsets have become available to the general public and virtual reality is one of environments suitable for digital simulation outcomes presentation and exploration, such as 3D scenes populated with dynamically simulated occupants.

3.4. Dynamic simulation methods for pedestrian and occupant models

Among existing methods used for digital simulations, those relevant to architecture and urban planning are pedestrian and occupant models. Both models are simulation models that represent the movement and behaviour of people in a specific environment.

Pedestrian models focus on public space, large objects and outdoor environments where flows of people need to be analysed to evaluate comfort, accessibility or safety, such as evacuation scenarios. Pedestrian models can be divided into microscopic and macroscopic. In microscopic models, a pedestrian is simulated as an individual interacting with others and the environment. He has personal characteristics and a decision-making ability. On the other hand, macroscopic models simulate pedestrians as groups and focus on aggregate behaviour of a crowd, which is considered to be fluid (Huang *et al.*, 2018).

Occupant models represent people inside buildings, such as offices, homes or schools to evaluate design with regard to comfort, energy efficiency, air quality or lightening.

There are multiple methods that can be applied in a simulation model. The fluid-based methods are common for macroscopic pedestrian models, meanwhile particle-based methods, cellular automata models and agent-based models are being used for microscopic ones. For occupant models, more complex agent-based models are suitable. One of these methods alone can hardly include all complex aspects of human behaviour including interactions between people and all static or dynamic elements in the space or the interaction between parallel processes in the same space. Therefore, according to the purpose of the simulation, different simulation methods and decision-making processes can be combined into a hybrid model to create a more realistic model of pedestrian or occupant behaviour.

3.4.1. Particle-based methods

Social force models consider pedestrians as homogeneous particles subject to physical and social forces of mutual attraction and repulsion (Helbing and Molnár, 1995). The model takes into account physical constraints such as collision avoidance and attraction to exits.

Another example of a particle-based method are potential-field models based on the concept of a potential field, where the goal is represented by a local minimum and obstacles are represented by local maxima. Pedestrians are modelled as particles that are attracted to the goal and repelled by obstacles, resulting in natural-looking motion. (He, Li and Lu, 2013)

3.4.2. Fluid-based methods

The fluid-based models use mathematical equations to model the movement of individuals in a crowd as a fluid-like flow. It is used to explore the behaviour of crowds, to understand how they move and respond to environment changes or to evaluate emergency evacuation (Wang *et al.*, 2013).

3.4.3. Cellular automata

In the cellular automata models, the environment is divided into a grid of cells. Each cell is assigned a state that represents the availability and suitability of that cell for pedestrian movement. The movement of pedestrians depends on a set of rules that govern how they interact with each other and the environment according to the state of the cells. These rules can be based on a variety of factors, such as pedestrian density, pedestrian speed, and the availability of paths. The model can be used to simulate evacuation scenarios, crowd dynamics, and pedestrian flow in urban areas (Li *et al.*, 2019).

3.4.4. Agent-based models (ABM)

A relevant principle of digital simulation of human spatial behaviour is agent-based modelling, where "a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules" (Bonabeau, 2002). ABMs are used in research fields dealing with biology, epidemiology, economics, sociology, robotics and many others. Originally for the field of ecology, the ODD protocol (Grimm *et al.*, 2006) was developed for the description of ABMs, which became a standardised format in all areas of application. ABM has the potential to help better understand human spatial behaviour, as it allows simulating dynamic processes including interactions of individuals with each other as well as interactions of individuals with the environment. With the help of ABMs, it is possible to realistically simulate the movements of pedestrians, where agents are attracted to a specified point in space, where they move along an optimal trajectory, but at the same time preserve their personal space (Crooks *et al.*, 2015).

There are a number of approaches to determine the behaviour of agents, while they can use more or less sophisticated elements of artificial intelligence. Most developed systems are built on a bottom-up strategy, where each agent has its own perception and decision-making abilities. Systems built on a top-down strategy, on the other hand, coordinate the behaviour of agents according to a fixed plan of activities. Some systems try to combine both strategies (Schaumann *et al.*, 2019).

Most common decision-making processes for pedestrian and occupant models are following:

- Rule-based

- Markov chain or Markov Decision Process
- Goal oriented action planning
- Narrative-based modelling
- Game-theoretic
- Reinforcement learning
- Artificial neural network

Multiple algorithms can be combined to achieve desired simulation properties.

Rule-based approach involves defining a set of predetermined rules or heuristics that describe how pedestrians behave in certain situations. Behaviour trees or Finite State Machines are common examples of this approach implementation. Behaviour trees are one of the most used techniques in the gaming industry. They are hierarchical structures that define the behaviour of an agent or system by representing a set of rules or conditions that dictate how the agent should act in different situations. It is suitable for the implementation of less complex behaviour patterns. With high complexity, they may no longer produce sufficiently realistic results. Finite State Machines is a mathematical model in which states and conditions to transfer between them are defined. One state is active at a given time and it is being executed until the condition for transition to another state is met. Simple examples of use are beverage vending machines, elevators or traffic lights. They are used in the development of non-player characters, but in complex systems they can become confusing and difficult to maintain.

Markov Chain is a mathematical model, where the conditions for state transition are not defined deterministically, but based on probabilities and the current state. It is a memoryless model, meaning the probability of each event only depends on the current state, not on the history of states that led to it. Kostas Cheliotis in his research on agent-based model of public space use (Cheliotis, 2020) applies the Markov Chain in the model of the decision-making process of agents, where three agent states are defined, namely movement, preparing for a stationary activity, and engaging in a stationary activity. A Markov Decision Process is an extension of a Markov chain that involves decision making. Each state is associated with a set of actions and each action has a corresponding reward and transition probability to the next state.

Goal Oriented Action Planning is a method developed for the gaming industry by Jeff Orkin (Orkin, 2008). In order to achieve a specified goal, a chain out of predefined activities is assembled. For each activity, there is a condition that must be met before the activity can occur. An outcome of the activity is then an effect on the state of the agent or the environment. Planning proceeds backwards from the specified goal by assigning possible activities to evaluate whether the goal is possible and how many possible solutions it has. Each activity is assigned its own price, in the case of several possible solutions, the algorithm makes a decision based on the sum of the prices of the activities in the given chain. It is more complex to implement compared to Behaviour trees, but can produce more dynamic and realistic results. Despite its popularity in game development, it is rarely implemented in pedestrian or occupant models.

Narrative-based modelling is based on creating a narrative, or a sequence of events, that describe how an agent acts and reacts in a particular environment. It tries to approximate the real behaviour of people in spaces where complex scenarios take place, such as in a hospital. It combines a bottom-up and top-down strategy, where each agent has a designated narrative to accomplish, but this can be interrupted by an unplanned narrative based on interactions that dynamically arise in the scene. After finishing the unplanned narrative, he continues to finish the planned one. (Schaumann *et al.*, 2019).

Game-theoretic approach models the interactions between pedestrians as a game, where pedestrians make decisions based on the actions and strategies of other pedestrians. (Amini, Dhamaniya and Antoniou, 2021)

Reinforcement Learning is a type of machine learning in which an agent learns to make decisions by performing actions in an environment and receiving rewards or punishments based on the consequences of those actions. Pedestrians learn to make better decisions by receiving rewards or penalties based on the outcome of their actions. Accurate navigation path with regard to obstacles and potential collision avoidance can be predicted (Trinh *et al.*, 2021). It is mostly being applied in research of autonomous driving systems.

Artificial Neural Networks (ANN) are a type of machine learning algorithm inspired by the structure and functioning of the human brain. They are capable of learning from data and making predictions or decisions based on that learning. Compared to previous decision making processes, ANN are coming with a number of benefits in simulation models development. First of all, a high level of flexibility enables easy adaptation to various scenarios and environments. It can capture subtle variations in behaviour patterns from large amounts of training data. Decisions trained on patterns on real world data can be more realistic than those based on predefined rules or heuristics. ANN can handle uncertain and incomplete data and generalise from the training data to new situations. Moreover, ANN can be combined with other types of models and decision-making processes while taking advantage of their strengths and overcoming their limitations. However, ANN in pedestrian models is a relatively new field of research and more development is needed to fully utilise the potential of these models. There are also some limitations to ANN use in pedestrian models, such as the need for large amounts of data and the difficulty of interpreting the model's decisions or significant computational resources required. Nevertheless, ANN are in tested scenarios already bringing more realistic pedestrian simulation results comparing to traditional social force model (Song *et al.*, 2018)

4. DIGITAL SIMULATION SOFTWARE TOOLS

There are multiple tools that can be used to develop a pedestrian or occupant simulation model. Pedestrian simulation is included in a number of agent-based modelling tools developed for a simulating transportation systems, such as SUMO (*Eclipse SUMO*, 2023) , Aimsun (*Aimsun*, 2023) or MATSim (*MATSim*, 2023) where hybrid models combining social force with rule-based processes are implemented. Aimsun as commercial software has a user-friendly interface with visual programming, two others require programming knowledge to build a simulation model. However, as these tools are optimised for transportation simulations, pedestrian models options are not sufficient to be used as auxiliary tools in the architectural design process.

Pathfinder (*Pathfinder*, 2023) is a software for simulating and evaluating evacuation scenarios in smaller buildings, but mostly in large objects, such as stadiums or stations. It is a standalone desktop application. A 3D model can be imported and a simplified model required for simulation manually extracted out of it. A user is working in a graphical user interface to set the properties of the 3D environment and population of agents. He can explore the simulation in 3D view or 2D outputs such as graphs. Though, as the purpose of the tool is to model evacuation, agents' behaviour is not complex enough to be useful as a design process tool to explore interactions between the proposed space and the users.

Anylogic (*AnyLogic: Simulation Modeling Software Tools & Solutions for Business*, 2023) is a commercial tool that seems to be one of the most suitable for pedestrian simulation modelling in architecture because of its flexibility to be implemented for various applications and wide range of features and libraries for pedestrians. A user-friendly interface with a graphical modelling tool allows to create models using drag-and--drop blocks for visual programming, therefore for simple models programming knowledge is not necessary. Still, development of the model is pretty complex, 3D is not fully supported and as there is no live-connection to softwares used by architects, it can be hardly expected to be used in common architectural practice.

Software tools for occupant models, such as IES (*IES Virtual Environment*, 2023) or CitySim (*CitySim Software*, 2023) are mostly being developed for the purposes of building performance, safety and comfort evaluation and optimization. They are a helpful tool for architects to optimise design for the best building performance, sustainability or to achieve one of the green building certifications. However, occupants, their movements, activities and interactions are mostly not visualised and therefore these kinds of tools are not suitable for exploring and evaluating direct impact of design changes on occupants' behaviour, well-being or interactions with proposed space.

Another option for creating a simulation model is to use a game engine with a combination of relevant plugins or assets. One of the most popular game engines is Unity (*Unity*, 2023). It is a powerful tool for creating interactive 3D models and simulations. There are a variety of plugins and assets available for Unity that can be used to create pedestrian and occupant models. These assets provide pre-built components for creating pedestrian models, such as steering behaviours, pathfinding, and animation. Additionally, Unity offers a wide range of capabilities for physics and lighting, which can be used to create realistic environments for pedestrian and occupant simulations. It is a suitable option for building more interactive and visually appealing models, but it requires programming knowledge and understanding of the unity engine. For implementing rule-based decision-making a visual scripting asset Behavior Designer

(*Behavior Designer*, 2023) allows to create behaviour trees for the agents. With flow charts of decisions and actions complex decision-making processes can be developed. Unity NavMesh allows agents to navigate intelligently around the environment. It includes pathfinding, enables avoiding static or dynamic obstacles and allows dynamic navigation mesh updates. There are also neural network based decision making assets, such as ML-Agents (Technologies, 2023) allowing the use of machine learning to train the agents. An Agent-Based Modelling Framework for Unity is being developed by Cheliotis (Cheliotis, 2021). With a fully 3D support, it might become a relevant tool in the field of architecture and urban design. However, so far it is still in the early stage of development. It also requires users to have a working knowledge of both Unity and C#.

5. 2D AND 3D SIMULATION ENVIRONMENT

Simulation methods of human behaviour are similar regardless whether the simulation is performed in a 2D or a 3D environment. However, pedestrian or occupant models can be very complex, especially in 3D. This complexity can make it more difficult to set up, run the model and to interpret the results in 3D. Another issue is data availability as 3D agent-based models require a lot of data. Collecting and processing this data can be a significant challenge. The availability and quality of the data can affect the accuracy of the simulation. An appropriate decision-making process must be chosen based on the available data and type of chosen environment. Considering validation, 3D models can be more difficult to validate, as it is harder to obtain real-world data complex enough to compare with the model predictions. This can make it difficult to assess the 3D model's accuracy. 3D models can be more realistic than 2D, but they can require more computational resources. Typically, available software tools are limited to 3D visualisations of the underlying 2D models.

Geometry needs to be often simplified to a limited number of acceptable types of elements, such planes in specified height levels and stairs or ramps connecting them (*Pathfinder User Manual*, 2023). Only a few platforms fully support the development of 3D models, whereas Unity is one of them.

CONCLUSION AND DISCUSSION

A number of existing approaches, methods and modelling tools were summarised in this paper. Pedestrian and occupant models are relevant for the field of architecture and urban planning. They can be based on various dynamic simulation methods including particle-based methods, fluid-based methods, cellular automata or the most appropriate agent-based models. In agent-based models, each individual agent is autonomous and has a decision-making ability. Multiple decision-making approaches can be applied, whereas the most common are rule-based, Markov Decision Process or artificial neural networks. A number of available software tools were introduced. There are tools appropriate for modelling pedestrian movements in transportation systems, for simulating evacuation scenarios or for optimising building performance. Only a few of them are more flexible and therefore seem suitable for broader use, namely Anylogic and Unity. Considering 2D or 3D model environments, simulations in 3D can bring more realistic results, however, they are more complex, require more data, can be harder to verify and more computational resources are needed to run the simulation.

After reviewing existing simulation methods, we might identify some of the reasons why digital simulations of human behaviour are not used in standard architectural and urban planning practices so far. First of all, the development of the simulation model is a complex process. A large amount of data is required, software licence is needed and a person without expertise is not capable of model development. Overall high costs for such a model development are mostly much higher than potential benefit for standard architectural projects. Other limitations are the properties of the existing tools. Most of them are focused on analysis and evaluation of traffic, evacuation, energy performance, building physics and not on exploration and evaluation of architectural qualities of proposed spaces. None of the appropriate tools is compatible or have a live connection to some of the CAD, 3D modelling or BIM tools commonly used by architects. An architect would therefore have to handle work in an unfamiliar interface requiring also programming knowledge. Another reason why architects do not use these simulation models can also be a lack of awareness. Most of the architects might not be aware of capabilities and potential benefits of using simulations during the design process.

A question is how we can make digital simulation of human behaviour more available and beneficial for architects and urban planners. Next steps might be to try to define parameters and properties of an ideal simulation tool for architects. A user interface of such a tool should be intuitive, interactive and easy to use. However, there is a question of complexity. Is it possible to include all important attributes of complex human behaviour while maintaining a user-friendly interface?

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MEMORABLE SPACE

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ABSTRACT

Learning in VR is always happening in a certain digital space. Inspired by memory techniques such as Method of Loci AKA Memory Palace, we propose to use a virtual reality (VR) 3D space as a form of Memory Palace which would enhance the learning process. These memory techniques use the strength of human spatial memory and attach new knowledge to spatial experience. The space we experience in VR would serve as a form of a memory palace, create multisensory experiences and thus enhance the learning process and help people to form deeper memory traces of learned topics.

Each learning topic would have dedicated a different VR environment which would be designed to be easily remembered and to correspond with the topic. To achieve desired efficiency we need easily remembered space, which would help to create rich episodic memory. It is also important for the environment not to disturb and attract too much attention from the learning topic. To find this thin line, we tested memorability of VR space through experiment with 9 different environments each deferring in certain parameters.

In this experiment we focused on the level of abstraction and detail of the scenes. Subjects walked through the environment in VR and were instructed to memorise two highlighted objects in each scene. Objects placed in the scenes were contextual and non-contextual in their environment, since it was expected that non-contextual objects would create more distinct scenes prone to be remembered. Afterwards we measured which objects and which location participants memorised the best. Results show that an environment with a middle level of abstraction and detail was easiest to remember, since it achieved a certain level of newness while being well comprehensible. As far as the objects are concerned it appears that even though an object is natural for its whole environment, it is the precise placement, which when is not logical, makes the object distinctive and easier to memorise.

Keywords: Memorable space, digital architecture, memory palace, VR, learning, memory

1. INTRODUCTION

Memory techniques such as memory palace are thousands of years old and serve people to memorise far stretching stories or poems (Yates, 1966). Their main advantage when compared with traditional methods of learning is their long lasting effect on memory capacity (Dresler et al., 2017). These techniques might be also very useful and efficient for learning new languages (Levin et al., 1992). However, a big disadvantage of these techniques is that they require quite extensive training. Therefore researchers test combinations of memory techniques with modern technology with the aim to make the memory techniques more accessible and user friendly. Especially potential is a VR technology with HMD headsets which mediates spatial experience with a high level of psychological presence (Bailenson, 2018).

Researchers who performed experiments with memory techniques in virtual environments achieved variable results such as work by J. Vindenes, Gortari & Wasson (2018) who performed a test with a virtual environment presented view PC screen and with VR setup with three degrees of freedom. Although their results showed some potential of using a virtual environment as a form of memory palace, the results didn't surpass traditional technique. One of the reasons was technological immaturity of the setup making too big obstacles for the subject to navigate VE. Also their VE design was fairly plain without any detail and probably didn't create a rich episodic experience which aids creation of a deeper memory trace (Eysenck & Keane, 2008).

Original Method of Loci was based on space which is well known to the person. In a virtual environment we presume that it is not the case since we use this VE only for the purpose of the method of loci. As Legge et al. (2012) present in their research it might now be an issue. Subjects in their experiment were able to achieve the same performance with use of previously unknown virtual environments when compared with control groups which relied on familiar space. Additional functionality such as the ability to manipulate the objects and create our own placement can boost the efficiency of the method as shown in the work of Reggente et al. (2020). They also used quite rich and unique environments which included landmarks and other elements of space suggesting that spatial qualities play also a vital role in efficiency of the method.

Our experiment was therefore focused on testing the idea of memorable qualities of space and on gathering insights how to approach this topic. We tested whether various levels of abstraction and detail are going to influence memorability of the space. Since human memory tends to remember unusual events and situations well, by changing the level of abstraction we slightly deformed realness of the environment and we observed whether this change is going to enhance memorability. We also tested whether objects placed outside of their natural context will be easier to remember for the same reasons.

2. PREPARATION OF AN VR ENVIRONMENT

2.1. Types of space

There were several different spaces designed for this experiment. They differed in level of abstraction and thus detail. Also three types of scenery were used making it in total nine different digital spaces. Graphic style for all the spaces was chosen as low-poly 3D without realistic textures, only colours. This graphics style was sufficient for good understanding of the space, keeping relatively low cognitive load and ensured good performance of the VR app on standalone VR headset. Size of all spaces was 10 x 10 metres which was adequate for a novel space explored by the participants within a given time frame.

First group of three environments with a low level of abstraction contained spaces which were created from low poly realistic 3D objects and were displayed with colours corresponding to reality, see Fig. 1: Abstraction - high. It was the most detailed version of space with the smallest objects being for example roof tiles and door knobs. It was expected that the "low" level would be easy to understand and would remind of a known space, however with relatively mundane scenes and regular objects wouldn't create strong memory traces.

The spaces with a high level of abstraction included environments which were created from geometrical shapes such as pyramids, cylinders and arches, see Fig. 1: Abstraction - low. Pastel colours underlined the

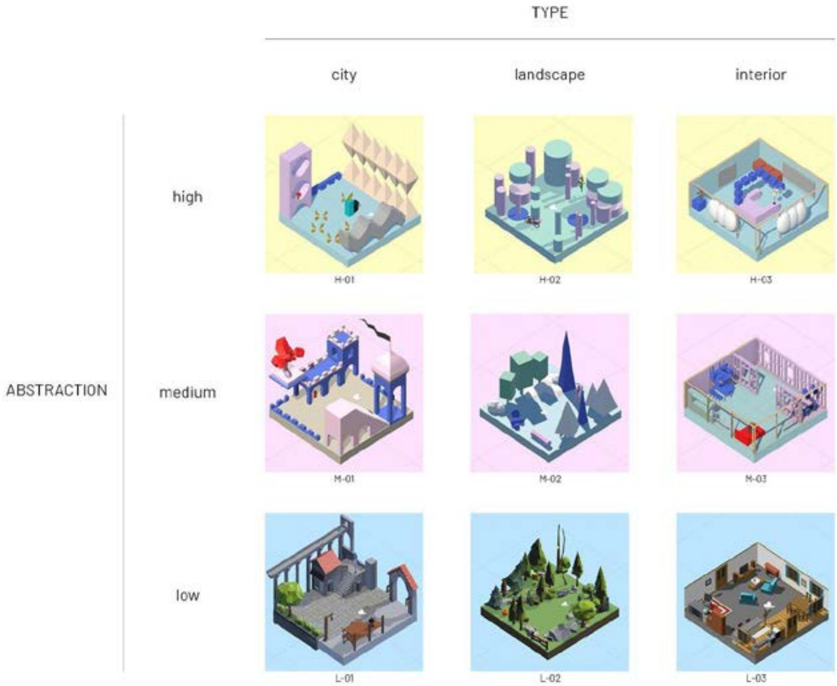

Figure 1: Overview of virtual reality environments used for the experiment.

impression of an abstract space which was quite unusual while relatively simple without many details. Unusual character of these abstract spaces was intentional to achieve certain newness and distinctiveness, since these experiences tend to be easiest to remember. It was however expected that harder recognizability and ability to name the space would create an obstacle in creating deep memory traces.

A level with a medium level of abstraction was intended to combine distinct and unusual features of "high" level and realistic parameters from the "low" level, see Fig. 1: Abstraction - medium. Ideally it would create an unusual and distinct space while being well recognizable and thus making it an ideal combination for memorable space. It was made of geometrical representations of real objects e.g. pyramid shape with a stick at the bottom representing a tree. Colours of scenery within "medium" level were slightly shifted from the normal and also positions of certain objects were slightly unusual.

To cover various sceneries and eliminate personal bias of the subjects we introduced three types of scenery: landscape, city and interior. Landscape consisted of various vegetation-like objects and was rather chaotic with many similar looking objects and harder for orientation. Therefore worse results in terms of memorability were expected. City scenes were created from elements of buildings and objects typical for cityscape, forming some sort of street or square. Interior scenes were enclosed by four walls and fitted with interior elements such as furniture etc. These latter two types were expected to perform similarly.

2.2. Objects

Two common objects were placed in each space, making it together eighteen objects. All these objects intended to be remembered by the subjects were highlighted by the pink outline, see Fig. 2.

Objects were selected from categories corresponding with three environment types used for the experiment, see Fig. 3. In each environment was located one contextual and one non-contextual object, see Fig. 4. Contextual meant it was somehow related to the type of scene. For example in the landscape scenery we had a flower as one of the contextual objects and a lamp as a non-contextual. It was expected that non-contextual objects would perform better than contextual since they create more bizarre situations.

Figure 2: Objects intended to be memorised were highlighted by a pink outline.

Figure 3: All 18 objects were related to three categories according to the environment types used for the experiment.

Figure 4: Contextual objects were thematically related to the environment, non-contextual were not.

2.3. Technical implementation

Digital space was presented via standalone VR headset Oculus Quest 2 (resolution: 3664 × 1920 px, refresh rate: 90Hz) with six degrees of freedom. The VR app was developed in the Unity game engine. Various libraries of 3D models were used for creation of the VR environment and 3D software Blender was used for editing and creating additional 3D models. Subjects were using one controller for the movement in the VR environments. The controller served as a pointing device which teleported the participant to desired location.

2.4. Learning procedure

Subjects were briefly instructed about the use of spatial memory within the learning process and about the principles of the memory palace technique by written introduction. Afterwards they put on a VR headset and went through a short intro explaining usage of VR controllers and movement within the digital space. Intro included a short task to ensure that all participants understand the main task and can navigate in the VR environment. Experiment itself consisted of nine spaces which were organised in one order, however each participant started at a different space

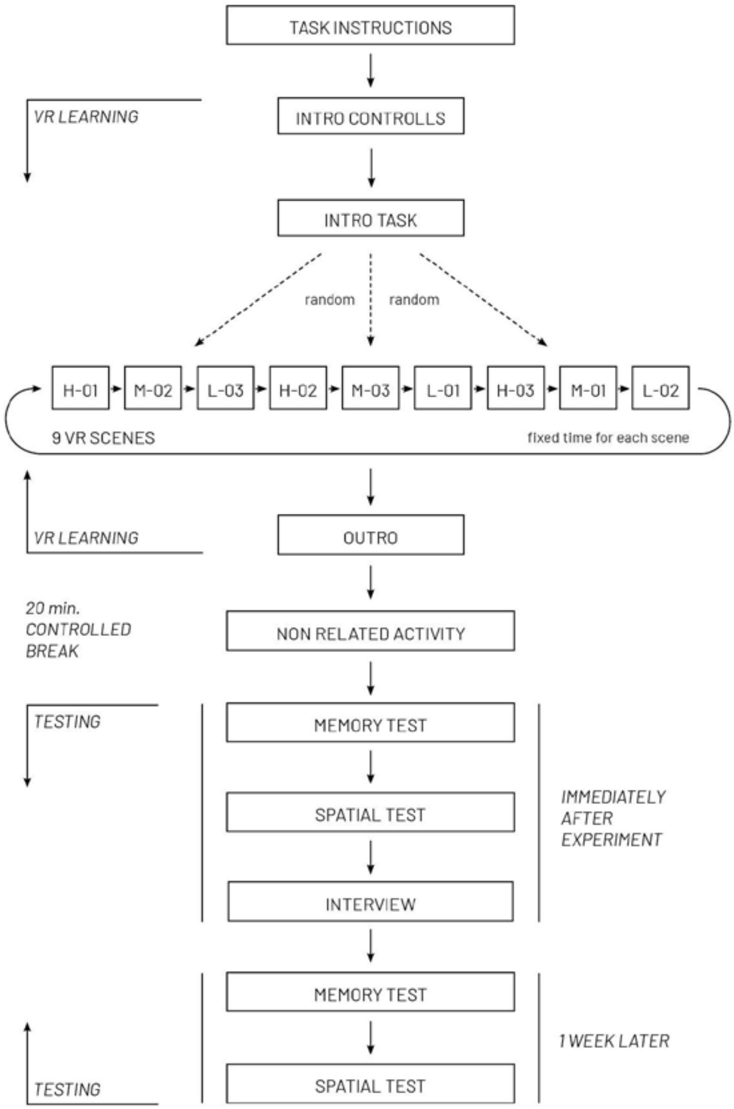

Figure 5: Schema of the whole experiment, which consisted of two main parts - VR learning and testing.

to eliminate the serial position effect (Murre & Dros, 2015). First scene was always selected by random. Scenes were switched automatically after 30 seconds during which participants had to identify two highlighted objects, name them aloud and then to memorise them within their spatial context, see Fig. 5.

2.5. Testing

After completing the VR session there was a 20 minute break when subjects continued in their previous activity, to clear short term memory (Eysenck & Keane, 2008). After the break they completed the first test. In the test we first collected general information about the subject such as age and if they experienced VR technology before. Then they were asked to name as many highlighted objects as they could (memory test). Afterwards they were presented each individual space with a grid dividing the space into 25 segments (placement test), see Fig. 6. Task was to identify in which segment the highlighted objects were placed and also name the correct object. Upon finishing the test we conducted a short interview and gathered individual insights from the participants, see Fig 5.

One week later, subjects received a second test form which again consisted of memory and placement tasks. Second test allowed to verify long term memory performance and create a forgetting curve. Total of 29 participants, aged 19-69 took part in the experiment (median age=28.1, 18 females).

3. RESULTING DATA AND INTERPRETATION

Data used for evaluation of the hypothesis were collected via tests conducted in the form of an online questionaire. Questionnaire contained a memory test, placement test and general questions about the participants

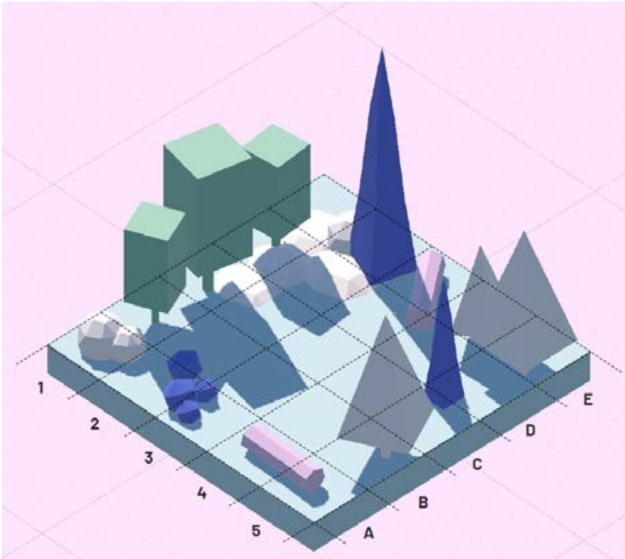

Figure 6: Axonometric view of the VR environments was divided into segments. Subjects assigned objects to specific segments.

and their experience with virtual reality technology and their awareness about memory techniques such as Memory Palace. We also gathered data on the movement of the participants in the virtual environment. Movement of the player in terms of rotation and location of the VR camera within the VR app was saved each 0.5 sec and exported as a json file after the end of the VR learning phase.

3.1. Memory

During the memory test, participants were supposed to write down as many objects as they can remember. One point was assigned for each correctly named object. There were in total 18 objects. Mean value by all 29 participants was 10,17 points, min. value = 5, max. value = 16.

Data from a memory test showed slightly better performance for medium space with 107 points, see Fig. 7. However data are rather inconsistent within the categories of space abstraction and do not make clear patterns. Rather we can observe hotspots of certain objects, which indicate that individual placement of the objects was more important for simple recall tasks than the environment as a whole. This was later confirmed in individual interviews, when participants stated that certain objects were either by their unusual appearance or placement prone to be memorised.

MEMORY TEST		TYPE						
		CITY		LANDSCAPE		INTERIOR		**TOGETHER**
ABSTRACTION	HIGH	mushroom	trash bin	corn	wheel	lamp	flower	
		12	12	22	16	11	24	97
	MEDIUM	hydrant	guitar	sheep	scooter	chair	stump	
		18	19	20	11	15	24	107
	LOW	bus stop	grill	pumpkin	microwave	washbasin	letterbox	
		17	9	10	19	20	16	91
	TOGETHER	87		98		110		

Figure 7: Results table from memory test.

3.2. Placement

Placement data also included precision of the placement. If the placement was precise, it was valued by two points. Fields right next to the correct one accounted for one point. If the subject correctly connected the environment with the corresponding object one extra point was added, making it total three points per position. Resulting data from these placement tests show significant differences between various spaces, see Fig. 8. As expected, the most abstract spaces performed the worst. Also in interviews subjects confirmed that even though it might have been an interesting space, it was hard to navigate and classify the space, which made it hard to remember. By 74% better were environments with low abstraction and the best performative were medium spaces with 247 points which was more than twice the score of the most abstract space category. While the results follow our expectations even in the placement test results we can see certain hotspots indicating that some objects performed significantly better than the other ones thanks to their individual position.

PLACEMENT TEST		TYPE						
		CITY		LANDSCAPE		INTERIOR		TOGETHER
ABSTRACTION	HIGH	mushroom	trash bin	corn	wheel	lamp	flower	
		30	15	13	18	18	19	113
	MEDIUM	hydrant	guitar	sheep	scooter	chair	stump	
		31	51	28	19	55	63	247
	LOW	bus stop	grill	pumpkin	microwave	washbasin	letterbox	
		55	31	16	26	45	24	197
	TOGETHER	213		120		224		

Figure 8: Results table from placement test.

3.3. Space types

Space type category showed differences for landscape, which performed significantly worse than the other two. It was partially expected and also interviews confirmed that a higher number of similar objects (trees, bushes) without strong hierarchy and composition created chaotic space which was hard to navigate and to create some sort of cognitive map. Therefore it was hard to connect an object with a location.

3.4. Contextual x non-contextual

Results show no differences between contextual and non-contextual objects. Even though we had some objects placed in the contextual environment their individual placement happened to be not logical and therefore made them easier to remember. Bus stop sign was for example placed in the city context, however it was placed on a platform only accessible by stairs which made it in the eyes of the participants illogical.

3.5. On week after

From the tests which were conducted one week after the VR session we can see only a very small decrease in the score. It indicates that relatively strong memory traces were created. Data from memory and placements tests remain consistent with data from previous testing.

4. CONCLUSION

Experiment again confirmed that we can indeed memorise a list of objects only by walking through digital space using VR headsets and to learn desired content, which is a rather entertaining form of learning. Intention to define first guidelines on how to design memorable space was partially successful. Experiment confirmed that certain distinctiveness of space is desired as seen in Fig. 8 - placement data. Environment with a medium level of abstraction achieved the best ratio between distinctiveness and recognizability making it a well memorizable space. It appears that it is also important to keep good orientation of the space with distinct landmarks, structured elements and clear composition. The results also indicated that individual logical or illogical placement of objects is very important and heavily influences memorability, which correlates with the original method of memory palace, which relies heavily on mnemonics. Digital architectonic space suitable for learning should provide opportunities to create these mnemonic situations. Aim was to gather insights on memorable space parameters which we defined at the beginning. Results correlated with initial expectations and confirmed our research questions. We conclude that according to the results, space which is combining unusual elements while being easily conceived and categorised is prone to be remembered.

5. DISCUSSION AND FUTURE WORK

To deepen the understanding of problematics we propose some improvements of the method. As presented in the result section there are some objects which performed well, but mainly due to their individual location and logical/illogical local context. It is also possible that because of harder recognizability of some of the objects they required higher cognitive effort and processing, therefore it created deeper memory traces. To gather cleaner data on the space parameters it would be desired to eliminate this local placement effect as much as possible. To achieve more precise results it would be also desired to measure the level of detail in the scene, to be able to equalise various environments and to isolate certain parameters. It could be measured by account of objects in the scene. Another option is to measure by polygon count, however this is quite problematic since mesh 3D objects can differ extensively in polygon count while not being more detailed.

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A REVIEW ON THE VIRTUAL EXHIBITIONS IN THE FIELDS OF ARCHITECTURE AND DESIGN

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ABSTRACT:

The concept of making its existence visible, felt, and remembered has been on the human agenda ever since the beginning of civilizations. This condition can be traced back to even centuries before, when cavemen drew on the walls of caves. People feel compelled to communicate what they have lived and accomplished to future generations, whether to impart knowledge or for any other reason. Over the years, a variety of approaches and places have been utilized for this purpose. In addition to traditional display places such as museums, galleries, and exhibition halls, virtual exhibition places became evident thanks to advanced digital technologies. With these virtual places, which require no physical space and can be 2D or 3D, the concept of exhibitions has taken on an entirely new dimension. People can examine the world's most significant works without even leaving their comfort zones. Similar technologies are also debated in architecture and design, which are fields in which exhibitions play a remarkable role. In the fields of architecture and design, where the majority of outputs are visual, displaying a design is just as important as creating it. Thus the concept of virtual exhibition emerges. Research proves, especially as a result of the pandemic, that many institutions hold their design exhibitions in virtual media. Accordingly, following questions are asked: How accurately can they be coded as places? What characteristics differentiate these virtual places from physical ones? Can or should a virtual exhibition space substitute for a real one? This study attempts to come up with some interpretation on these questions. In the scope of this paper, a total of 50 virtual exhibitions from different locations of the world, held in the fields of architecture and design were investigated and categorized, to basically form a critical approach on them. This research intends to serve as a reference for future virtual exhibitions in the domains of architecture and design.

Keywords: Exhibition, Virtual Exhibition, Architecture, Design

1. INTRODUCTION

It is known that the vast majority of architectural and design products are visually oriented. Consequently, the way of presenting the outcomes is as essential as the idea or project itself. Accordingly, the presentation methods of the projects and the environment in which they are presented are of great importance. At this point, exhibition places come to mind. With the factors such as globalization, networking, development of technology and internet, opened a new chapter for exhibitions. Although exhibiting a product, art, or even lifestyle was on the human agenda for its existence, the factors given above was key to a paradigm shift. The people who exhibit their products, had, or has to give answers and solutions to this paradigm shift happening on the field of exhibition. As in many disciplines, exhibition also evolves into virtual platforms. Although the concept of virtual exhibition has been on the agenda for many years and has been the subject of many different academic studies, it still cannot fully reflect its potential. This concept comes to the fore especially in museums or important touristic structures. However, number of studies conducted specifically at universities and design fields is quite few.

This research consists of four distinct sections in which the notion of virtual exhibition, which has begun to be met regularly after Covid-19, is processed through design disciplines. In the first section, the study's objective, the types of topics it addressed, and its methodology were described. In the second section, instances of how the notion of exhibition and virtual exhibition is transmitted in the literature are highlighted, and in the third section, virtual exhibition place examples built by universities from all over the world are analyzed. In the results, the conclusions obtained from this research were presented. In the last part, some recommendations for future virtual exhibitions have been given.

1.1 Aim of the Study

This study aims to produce a resource for the related fields such as architecture, design disciplines and exhibition. The study also seeks to define exhibition and virtual exhibition, as well as identify which products qualify as *virtual exhibitions*. It is anticipated that some conclusions will be reached on what future virtual exhibitions should pay attention to.

1.2 Research Questions

Research questions of this study are listed below:

- What is a virtual exhibition, how is it defined in the literature?
- What are the concepts that make the virtual exhibition *virtual*?

- Is the virtual exhibition different from the physical exhibition or should it be?
- Can the virtual exhibition replace the physical exhibition?
- What are the examples of virtual exhibitions in the world, and what are the common and different features in them?
- What are the most used programs or methods in virtual exhibitions?
- What are the points to be considered in future virtual exhibitions?

1.3 Methodology

In order to find answers to the research questions above, it was decided to examine virtual exhibition samples from different parts of the world. The main method used to reach different virtual exhibition examples from around the world is to search via Google and Google Scholar. The keywords used while searching are "virtual exhibitions", "virtual exhibitions in design, "virtual exhibitions in architecture", "virtual exhibitions in design fields", "virtual exhibitions in university". At this point, the use of Google is important in terms of accessibility. In certain instances, the virtual exhibition samples may be accessible directly from the university websites, while in others, they could be obtained via the sources of distinct works. Initially, emphasis was placed on Turkish institutions, followed by a search for English-language materials from a variety of places throughout the world. As a consequence of the study conducted on Google and Google Scholar, several instances of virtual exhibitions have been found. However, only examples related to the subject of architecture and design were studied among those discovered. Of these, those belonging to the universities selected. As a result, 50 different virtual exhibitions from design faculties of universities around the world were determined as the sample of the study.

2. VIRTUAL EXHIBITION

One might say that the notion of exhibition has been on the human agenda from the beginning of time. Therefore, the place where the exhibition will be held has kept its significance throughout history. Depending on the growing technology, it has been noted that physical places can be replaced by virtual ones. It might be claimed that the exhibition may or is going through similar stages. With the virtual exhibition venues, the locations have become relatively unimportant. Technology reduces the distances and brings different cultures together. It has been argued that virtual exhibitions possess features like localization, relevance, interactivity, maintainability, and accessibility (Dumitrestu et al, 2014). When building virtual exhibitions, it is essential to adhere to and not disregard these features. According to the same study, virtual displays may be planned or modified more quickly than physical ones. This was also seen as a favorable aspect. Additionaly, Ciruera et al (2016) state that virtual exhibitions offer several advantages over real ones. These include the quick reutilization of the space, the absence of a security risk for the objects on display, and the decreased cost. With these positive aspects, it is one of the questions that has been asked for many years whether virtual exhibitions can replace physical exhibitions. For instance, in his study, Lester examined whether virtual exhibitions may replace physical ones (2006). The author argued that the exhibition indirectly interacts with its visitors by virtue of the fact that it itself, in a way, a form of communication. Lester stated in the same research that a virtual exhibition cannot be *real* in the strictest meaning of the word, however he mentioned that the visitor has considerably more flexibility in the virtual world. In this way, both cannot be substituted for one another, but their good and negative characteristics mutually reinforce one another.

Museums are one of the first thoughts that spring to mind when considering virtual exhibitions. Prior to Covid, virtual museums and online exhibitions, whose relevance has expanded as a result of the inability of individuals to leave their homes, particularly during the epidemic, have been the focus of academic research. First to suggest the concept of a *virtual museum* was Andre Malraux. As a notion, he conceived of a museum without physical bounds in 1947 (Roedere et al, 2020). Sylaiou et al (2010) claim that in virtual museum environments, the content should be attractive and enjoyable enough to get the people's attention and curiosity. Because of that they came up with a system called ARCO (Augmented Representation of Cultural Objects), which they combine 3D elements and web databases with the physcial space. With the help of this technology, visitors can feel presence in the museum, and experience the place as if they are in the real one. Besides from the fact that exhibition places serve for exhibiting a product, they should offer an experience. In today's world, museum and other exhibition places changed their approach to more "visitor-orinted" style which the visitor, and the experience he or she had in the exhibition place is the main goal (Kamariotou, 2021). Perhaps one of the most important ways to achieve this goal is to present something to the visitor so that he or she can enjoy and feel encouraged to visit the space. The exhibition place should not be a space for only to exhibit products in boring and old-fashioned way. Throughout the development of the exhibition, the exhibitor must interact with the users (Hertzum, 1999). In fact, people visiting the exhibition should be able to talk among themselves or interact with each other (Elgammal et al, 2020). A virtual exhibition should not only replicate and transmit real ones, but also create new exhibitions and interaction areas (Giaccardi, 2006). According to Serafin (2004), emphasis should be made to aural factors too while building virtual places. It has been found that the auditory aspects, which is one of the variations between the actual world and the virtual environment, are overlooked in several research; thus, it is believed that this problem should also be stressed. Similarly, another research found that the factor of a sensation of being there is equally significant (Hofler, 2021). The individual witnessing the virtual presentation desires a sense of presence. He believed that this could be accomplished by feeling like walking in that environment and having the sensation of touching something.

In another research, students were tasked with designing an exhibition space to display their products (Campanile et al, 2021). Consequently, a collective product arose. Students described this area as a *project that exhibits other projects* and noted that the exhibition place had become an exhibiting product. -In this regard, it can be concluded that the design of the exhibition has a very important role as well as the items utilized in there. In their 2021 project, Pinandita et al created a virtual exhibition space during the pandemic. This place, which was not constrained by the constraints of physical space and time, provided students and other visitors a more engaging experience. Another example is done by Stavrev (2021) who constructed a virtual exhibition room in his work. In this place, where visitors may teleport from one location to another with the press of a single button, it has been feasible to save time and explore the place more rapidly. In addition, the author believes that traversing a virtual area unrestricted by the real space's constraints might expose the creative potential of architects and interior architects.

An emerging branch of virtual exhibitions consists of educational institutions' virtual exhibitions that have come into prominence after the start of the mandatory online education period due to the Covid-19 pandemic. Many universities, especially architecture and design schools, have started to look for methods to transfer their conventional physical exhibition methods into the virtual world.

As can be seen from the paragraphs above, there are many studies on virtual spaces and exhibitions. However, the number of studies examining these spaces in the discipline of design is very few. The section examining the examples connecting these two main disciplines is given below.

3. VIRTUAL EXHIBITION EXAMPLES

A total of 50 virtual exhibitions in the field of architecture and design from universities selected. These analyzed virtual exhibitions are detailed in Table 1. The table includes details such as the exhibition's opening year, university, nation, and department. In addition to this, the table also includes the tools and procedures utilized for the virtual exhibition. The table has been organized by year in order to make it easier to understand. Finally, website links to virtual exhibitions have been included in the appendix in numerical order so that readers can access if they want to.

Table 1: A sample table of virtual exhibitions around the world

#	Year	University	Country	Field	Content	Tool	Method
1	2022	Bahçeşehir University	Turkey	Faculty of Architecture and Design	3D Model	Istaging	Designed Place
2	2022	Istanbul Kültür University	USA	Architecture, Design, Fine Arts	Website	-	-
3	2022	California College of the Arts	Turkey	Department of Interior Architecture	Website	-	-
4	2022	Mimar Sinan Fine Arts University	UK	Department of Architecture	Website	-	-

#	Year	University	Country	Field	Content	Tool	Method
5	2022	Welsh School of Architecture	UK	Faculty of Engineering	Website	-	-
6	2022	University of Nottingham	USA	Visual Art + Graphic Design	Website	-	-
#	Year	University	Country	Field	Content	Tool	Method
7	2022	Point Loma Nazarene University	USA	School of Design / School of Public Architecture	Website	Issuu	-
8	2022	Michael Graves Col-lege at Kean University	Turkey	Department of Architecture	Website	-	-
9	2022	Bur-sa Uludağ University	Turkey	Department of Architecture	Website	Anyflip	PDF catalogue
10	2021	Yeditepe University	Turkey	Department of Visual Commu-nation Design	Website	-	-
11	2021	Anta-lya Bilim University	Turkey	Faculty of Fine Arts and Architecture	3D Model	Artsteps	Ready Template
12	2021	Emily Carr University of Art and Design	Canada	Communication Design, Interac-tion Design, In-dustrial Design	Website	-	-
13	2021	Eastern Mediterrian University	Turkey	Department of Architecture	3D Model	Artsteps	Ready Template
14	2021	Carne-gie Mellon University	USA	Thesis students of Architecture	Website	-	-
15	2021	Columbia Graduate School	USA	Architecture; Urban Design; Urban Plan-ning; Historic Preservation	Website	-	-

#	Year	University	Country	Field	Content	Tool	Method
16	2021	Pratt Institute of Architecture	USA	School of Architecture, Design	Website	-	-
17	2021	Tulane School of Architecture	USA	Thesis students of Architecture	3D Model	Unity WebGL	Real Place
18	2021	UIC School of Architecture	USA	Department of Architecture	Website	Miro	-
19	2021	University of Michigan	USA	Department of Architecture and Urban Planning	Website	-	-
20	2021	University of Pennsylvania	USA	Department of Fine Arts	Website	-	-
21	2021	USC School of Architecture	USA	Faculty of Architecture	Website	-	-
22	2021	Washington University	USA	Department of Architecture and Urban Design	Website	-	-
23	2021	Yale School of Architecture	USA	Department of Architecture	Website	-	-
24	2021	Karadeniz Technical University	Turkey	Department of Architecture	3D Model	Artsteps	Ready Template
25	2021	Erciyes University	Turkey	Department of Architecture	3D Model	Artsteps	Ready Template
26	2021	Beykent University	Turkey	Department of Architecture	Website	-	-
27	2021	Hasan Kalyoncu University	Turkey	Department of Architecture	Website	-	-
28	2021	Kadir Has University	Turkey	Faculty of Architecture and Design	Website	-	-

#	Year	University	Country	Field	Content	Tool	Method
29	2021	Istanbul Technical University	Turkey	Faculty of Architecture	3D Model	Unity WebGL	Real Place
30	2021	Okan University	Turkey	Department of Interior Architecture	Video	Youtube	-
31	2021	Yıldız Technical University	Turkey	Department of Architecture	Website	Blog-spot	-
32	2021	Özyeğin University	Turkey	Department of Architecture	3D Model	Artsteps	Ready Template
33	2021	Atatürk University	Turkey	Landscape Archi-tecture Studio	3D Model	Artsteps	Ready Template
34	2021	The Barlett School of Architecture	UK	Master of Architecture	3D Model	-	Ready Template
35	2021	Daekin University	Austra-lia	School of Archi-tecture and Built Environment	3D Mod-el-Scan	3D Scanning	Real Place
36	2021	Lebanese American University	Lebanon	Department of Architecture and Interior Design	Website	-	-
37	2021	Rmit University	Austra-lia	Faculty of Architecture	Website	Miro-Con-cept board	-
38	2021	Çankaya University	Turkey	Department of Interior Architecture	Website	Google Docs - You-tube	-
39	2020	Monash University	Austra-lia	Faculty of Art, Architecture and Design	Website	-	-
40	2020	Lund University	Sweden	Architecture Master Studio	Website	Miro	-

#	Year	University	Country	Field	Content	Tool	Method
41	2020	University of Capetown	South Africa	School of Architecture, Planning & Geomatics	Website	Anyflip	PDF catalogue
42	2020	University Johannesburg	South Africa	Department of Architecture	Video	Youtube	-
43	2020	University of Nocias	Cyprus	Department of Architecture	3D Model	360 Goterest	Real Place
44	2020	University of Florida	USA	School of Art + Art History	Website	-	-
45	2020	Grand Valley S. University	USA	Graphic Design	Website	-	-
#	Year	University	Country	Field	Content	Tool	Method
46	2020	Henry Ford College	USA	Digital and Graphic Arts	3D Model	Artsteps	Ready Template
47	2020	Ferris State University	USA	Collage of Art and Design	Website	-	-
48	2020	California State University, Fresno	USA	Department of Art, Design and Art History	3D Model	Hubs Mozilla	Ready Template
49	2020	Michigan State University	USA	Graphic Design	Website	Instagram	-
50	2020	Edinboro University	USA	Graphic and Interactive Design	3D Model	Kunstmatrix	Ready Template

4. RESULTS

All fifty virtual exhibitions analyzed for this study were created after the year 2020. It is believed that this is mostly due to the fact that many universities have moved their operations to the virtual environment after

Covid-19. By research methodology, it was not feasible to access the virtual exhibitions created before 2020. Although it is for certain that there were virtual exhibitions which were created before 2020, it was not as accesible as others. In addition, it was determined that the 50 sources discovered were adequate to draw consistent conclusions, and it was chosen not to include the relatively few examples which completed before 2020.

USA had 19 examples of virtual exhibitions in the research, the most of any country. After USA, the country with the highest number of virtual exhibition examples in the study was Turkey with number of 18. It is believed that the primary reason for this is that in addition to searching using English keywords, searches are also conducted in Turkish. For example, research has been carried out with keywords such as *sanal sergi*, which means virtual exhibition in Turkish. In addition to these two countries, three samples each from Australia and United Kingdom, two samples from South Africa, one sample from Canada, one sample from Lebanon, one sample from Sweden and one sample from Cyprus were examined. There is no consistent relationship between countries in terms of the method or content used in virtual exhibitions. 38 of the examined virtual exhibitions are in the architecture and design or related faculties of their universities. The remaining 12 are in sections such as graphic design, digital arts, and art history.

Based on the method used, it was concluded that 33 virtual exhibition examples were created on a single website. Again, it was established that the most common strategy in these samples was to display student names and visuals from the project. It is possible to examine the student project with one click without the need for any other command. Additionally, it has been established that programs like *Miro* are utilized. Thus, it is possible to view all projects on a single screen and zoom in or out as needed. Moreover, if Miro permits online usage, it is possible to observe other people watching the display, if only as a cursor. This arrangement improves interaction significantly and attracts attention. In addition, it has been observed that programs such as *Anyflip* are used and the projects are exhibited as if they were exhibited in a physical catalog or magazine. With this program, it is possible to switch between pages. It was established that two institutions released *YouTube* videos of their exhibitions. In addition to Youtube, it was found interesting that social media programs such as *Instagram* were also used for the virtual exhibition. It is another example that intermediate programs or services such as *Artsteps* and *Hubs Mozilla* that give ready-made templates and assist virtual displays are also employed. Numerous colleges utilize Artsteps, a web-based tool that allows users to build three-dimensional spaces/exhibitions using a fairly easy interface. In addition to two-dimensional photos and movies, this tool can accommodate three-dimensional models. Additionally, browsing and viewing exhibits created by other users is one of the options offered. Thus, a more social platform is developed. In addition to being able to build their own places in relatively basic ways, users may also use ready templates. Such applications provide approaches that ease and speed the model preparation process. However, because to the restrictions of the qualities they give, the formation of places that are quite similar to each other is a remarkable circumstance of this study.

15 universities created 3D models for their virtual displays. One of them (Daekin University) created the display by scanning actual studios in 3D and uploading them to a computer environment. Others have employed entirely computerized exhibition spaces. Three of them (Istanbul Technical University, Tulane School of Architecture and University of Nocias) mimicked their genuine spaces. Others used the ready-made places registered on the program they used. Only one of the examined exhibitions (Bahçeşehir University) realized its exhibition in a completely fictional and designed virtual place. It can be said that this situation is

important in terms of attracting the attention of the exhibition visitors and distinguishing it from other examples.

5. CONCLUSION

In this study, which focuses on the concept of virtual exhibition, first, readings on exhibition and what virtual exhibition is, are conveyed. The research investigated a total of fifty virtual exhibitions from across the world. All of the analyzed virtual exhibitions pertain to the fields of architecture and design and were created by universities. Based on the literature review and the examples examined, the points that should be considered in the virtual exhibitions to be held from now on are analyized below in three different sections:

Virtual Environment:

Obviously, virtual exhibitions are generated in a very different atmosphere than real ones. However, it should not be forgotten that both serve the same aim, which is to display the developed product in the most engaging manner possible. It should not be forgotten that the participants experience the virtual exhibition in a similar way as they visit a museum or exhibition hall in real life, and the venue should be designed accordingly. The design of the virtual exhibition is as important as its content. Again, visitors may prefer places specially designed for this aim instead of existing ones. The exhibiton place became an exhibiting product itself. Placing some 3D models, or even trees, green elements may have a positive affect on the visitors.

Content:

Virtual exhibits can use technologies like VR, which are becoming increasingly popular nowadays. Thus, it is possible to ensure that the exhibitions are more engaging and interactive. In this way, the visitor turns into a person who directly participates in the exhibition, rather than just a spectator. The use of three-dimensional products such as models, apart from only two-dimensional products such as posters, can make the exhibition more interesting. In addition to the visual elements, the addition of auditory elements plays an important role in the perception of the virtual space and the exhibition. Similarly, the place can be made more interesting with sound. Virtual exhibitions shall act as social media platforms. Information such as how many people see the exhibited product shall be added to the exhibition. Visitors shall like and comment on the projects they want. Sufficient information should be given in the virtual exhibition. Unnecessary information that will bore the participant should be avoided. An entire exhibition should neither be short enough to be completed in 1 minute, nor should it be large enough to last for hours. Although the size of the exhibition may vary according to its content, its duration should be adjusted to keep the participant's interest at the highest level. The content of the links to be given in the virtual exhibition should be carefully selected. Links that are considered important should be included, and it is recommended to open a new window within itself rather than directing them to other pages. Virtual exhibitions should be available through mobile devices or tablets, rather than just a computer. In this way, it will be easier to reach as many audiences as possible. People can visit the places whenever and whereever they want.

Navigation:

It is possible to guide those who visit the exhibition with previously determined arrow keys or images. However, the balance between this situation and leaving the visitor completely free must be well maintained. Neither completely liberating nor completely directing will solve the problem. It may be better to have the exhibition space experience as a group rather than to experience it alone. Programs that allow this can be used while designing the exhibition. For instance, each visitor can have their own avatar or their own name which can be seen from other visitors. It may also be interesting that the exhibition has a time in itself. It can be interesting for visitors to experience the transition from day to night or from night to day.

The notion of virtual exhibition, which has acquired prominence because to the epidemic, will apparently be permanent in the future. The fact that the epidemic is gradually losing its impact does not appear to change the current scenario. Now that everything is transitioning to the digital realm, perhaps there will be more virtual exhibitions in our future. This study aims to serve as a reference for future research on related topics.

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APPENDIX

Link 1: https://www.istaging.com/zh-cn/CustomerSuccessStories/innovative-university-embraces-metaverse-technology-host-virtual-exhibition/

Link 2: https://portal.cca.edu/showcase/2022/?division[0]=Architecture%20 Division

Link 3: https://sanal-sergi.msgsu.edu.tr/ic-mimarlik-bolumu-dijital-sergisi/

Link 4: https://wsa-ondisplay.co.uk/2022/explore/

Link 5: https://www.nottingham.ac.uk/engineering/architecture-exhibition/exhibit-2022.aspx

Link 6: https://www.plnuseniorshow.com/

Link 7: https://www.michaelgravescollegereview.com/

Link 8: https://uludag.edu.tr/mimarlikbolumu/konu/view?id=7330&title=mimari-tasarim-1

Link 9: https://mim.iku.edu.tr/en/events/virtual-architectural-design-exhibition

Link 10: https://vcdyeditepe.wixsite.com/mixed2021

Link 11: https://www.antalya.edu.tr/index.php/en/faculty-and-departments/departments/ic-mimarlik-ve-cevre-tasarimi/content/virtual-exhibition/virtual-exhibition-4th-class/iaed-4002-virtual-exhibition

Link 12: https://theshow.ecuad.ca/

Link 13: https://www.artsteps.com/view/5ebd625d9df06a42985c3c64

Link 14: https://thesis.soa.cmu.edu/Themes

Link 15: https://www.arch.columbia.edu/eoys-2021

Link 16: https://prattshows.pratt.edu/2021

Link 17: https://architecture.tulane.edu/research-work/thesis/2021

Link 18: https://miro.com/app/board/o9J_lFkafmk=/

Link 19: https://taubman.show/

Link 20: https://www.design.upenn.edu/yes2021
Link 21: https://expo.uscarch.com/spring-2021/
Link 22: https://2021yearendshow.myportfolio.com/
Link 23: https://www.architecture.yale.edu/exhibitions/72-t-o-g-e-t-h-e-r
Link 24: https://www.artsteps.com/view/60ae26879e753e3140e40d8e?curren-tUser
Link 25: https://mimarlik.erciyes.edu.tr/etkinlik/mimarlik-bolumu-pandemi-donemi-proje-sergisi
Link 26: https://www.beykent.edu.tr/dijital-sergiler/2021-2022-guz-donemi-mi-marlik-bolumu-ogrencileri-karma-sergisi
Link 27: https://mim.hku.edu.tr/sergi/
Link 28: https://fadport.khas.edu.tr/
Link 29: https://mim.itu.edu.tr/wp-content/uploads/taskisla/WebGL_2122G_ProjeDersleri/index.html
Link 30: https://www.youtube.com/watch?v=rFhLVZapJMk&t=164s
Link 31: https://ytumim2020guzsergi.blogspot.com/
Link 32: https://www.artsteps.com/view/5eb6874877b4156f9ba9f444
Link 33: https://www.artsteps.com/view/620f99a8495e73f6183e4c82
Link 34: https://bpro2021.bartlettarchucl.com/
Link 35: https://my.matterport.com/show/?m=oTzqteHXTNo
Link 36: https://daidexhibition.com/
Link 37: https://rmitarchitecture-exhibition.net/
Link 38: https://docs.google.com/presentation/d/e/2PACX-1vSenasMEuBKGvgTiRVzQxhzy2CSuH69GgQHDnxRtkRcVpdYDeNZweER3Zb0KbpJPf_HArEZWPeNhKGT/pub?start=true&loop=true&delayms=60000&slide=id.p
Link 39: https://www.monash.edu/mada/student-work/madanow2020
Link 40: https://miro.com/app/board/o9J_lYV8KXE=/?fromEmbed=1
Link 41: http://www.apg.uct.ac.za/apg/virtual-exhibition-bas-honours-2020-vir-tual-architecture-exhibition

Link 42: https://www.youtube.com/watch?v=WKV7dbtrJrs&ab_channel=UniversityofJohannesburgofficialYoutube
Link 43: https://360.goterest.com/sphere/arc-exhibition-final?scene=5ef0bd2effd0e12a2ca5bc82
Link 44: https://www.2020.ufdesigners.com/
Link 45: https://gvsugd.cargo.site/
Link 46: https://www.artsteps.com/view/5eb42a61a8b4fa2382e0a533?fbclid=IwAR3dXxUo7Xs9U9NjTSGDRJ5aASQ3lRTux0cRucg6pGhPpdvXHuwFA5_vvVs
Link 47: https://www.kcad2020.org/ug
Link 48: https://hubs.mozilla.com/PQ86sDP/fresno-state-art-and-design-gallery
Link 49: https://www.instagram.com/design_showcase2020/
Link 50: https://artspaces.kunstmatrix.com/en/exhibition/797501/m-i-x-e-d-t-y-p-e-gid-senior-show-20

MEMORY AND SPACE IN PAST, NOW AND THEN: COLLECTIVE MEMORY IN DIGITAL AGE

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ABSTRACT

Paradigms on the concept of space correlates with many different subcategories and being addressed from various disciplines with distinctive prospects. Although it may seem that these discernments correspond to entirely different aspects of space, ultimately in the deeper level of interrogations they are considerably related with each other. Over the years, with the developments in technology, how we engage and interact with world, how we get informed and experience the space is substantially being affected. The way we live in the digital era and the in-dept query of the phenomenon of space in digitalization shifts the conventional spatial cognition. Consequently, the correlation between space, experiencing mind, and the memory are being mediated by the modalities of digital mantras. The memory is no longer restricted with what mind can archive or recall. Memory formation according to the latest neurocognitive theories can be stimulated digitally as well as material constituents in which the digital map can imitate the representation of external objects and eventually can alter the way of perception (van Dijck, 2007). This study intends to unfold the phenomena of memory and space and their interrelations departing from the formation of space and spatial paradigms, then utilizes the perception processes of space and spatial experience with collective memory. Furthermore, within the limits of memory and history, one of the main focus of this paper is to elaborate the cognition of space in conventional and digitized sense. Either individually or collectively, storing trails of the experiences has been transformed by the digital technologies (García-Gavilanes et al, 2017). With the insights of these theoretical conjunctures, study aims to present possible future projections of these notions towards digitalization. The notion of collective memory in the context of digitalization is discussed over a data sculpture artwork installation of Turkey based artist as Melting Memories by the artist Refik Anadol. Furthermore, with respect to traditional apperceptions, study scrutinize the methods of memory accumulation and representation in digital age.

Keywords: Spatial perception, spatial cognition, collective memory, digitalized memory, digital memory.

1. FORMATION OF SPACE

The space is both a physical content and a product of mind in which it corresponds the perceptual aspects of the world; a notion that open to transformation through the designers whereas also constitutes mental processes besides the formation of the architectural product's generation even though the outcome product corresponds to it (Forty, 2000). Although formation of space corresponds many different prospects, in its very essence it accommodates a user, an activity or motion, and an enclosure where the actions take place. Throughout the examination of formation, the roles of each constituent of the concept and their connotations are probed. Space, volume, and the sense of space in the formative notion are structured through one's level of perception, emotion, and consciousness along with the necessities of time (Gezer, 2012). If we do not think of a defined space as empty for a moment, we see that the space contains things that are not individually a thing or a material object; then the space ceases to be a floating 'environment', a simple abstraction or pure form, because it has a content (Lefebvre, 1991). It can be suggested that the phenomenon that makes the definition and existence of space not an abstract concept is the totality of objects that the space includes and contains. The meaning of elements of space hence the space itself resides in the interrelations and interplays that corresponds precise codes within the mind. According to Lefebvre (1991), space is a set of relationships between objects and products. With his insight, is it possible to say that the space as a singular concept is a phenomenon that we cannot reconcile with reality, but when it is perceived as an enclosure that allows the activity and shelters individual parts within, space can be formulated as spatial being. Due to the fact that space is an outcome of a mind through certain processes, to fully comprehend the space itself and its reverberations, the processes which lead the formation of space should be analyzed.

Tackling with the essential constituents of formative space as irrefutable parts of the whole and making inferences from them both strengthens and qualifies the definition of space and employs on to reach the formation of space. Utilizing a holistic theory to unveil the formation of space might provide tangible prospects. Thinking in abstract sense, some spaces are just abstractions; nevertheless, as material abstractions, they derive their 'real' existence from networks and paths, relationship accumulations and clusters (Lefebvre, 1991). Departing from here, since the space is based on social environment in terms of its formation, design processes entail contextuality and narrative.

2. DECODING THE SPACE

Decode or decipher can be defined as converting a coded message to a recognizable form (Merriam-Webster), whereas encoding indicates a process of transforming data from one another (Christensson, 2010). Although these terms mostly evoke technological data processing language, in its very essence they can correspond to a generic usage. Moreover, since the issue of this study is to rationalize the meaning the space possess, terms and their inferences can be implemented. The components of space whether it is an object or a mere vision, along with the spatial perception we are decoding the conveyed messages either with beholding, or through sensations. Therefore, it can be suggested that in a way, through our body, senses, and mind, we are sometimes decoding the messages in an intelligible sense and sometimes encoding through projecting onto space itself. In either case, there is a transmittance and a cycle between the space and the human body.

According to Toprakkaya (2007) Kant suggests that the knowledge of the apparent world is entirely real, and the perceptual conception and vision are not the inaccurate type of knowledge, on the contrary; they are one of the sources of the knowledge. Since the fundamental inputs of the utilized space theory involves active participation of user, the concepts of vision and notion should be elaborated. Another issue that should be considered regarding the definition of the space is the unity of the space with the individual. For when we design the space as a mental thing, how can we connect it with the outside of the mind, that is, with the world or nature? (Kurtar, 2012). The act of designing as an abstract concept is directly related to the user in the context of concretizing the designed space. Some visual and mental elements offered to user through the designed space within the scope of this relationship are effective in assimilation of the space by its user. Architectural space in mental level is associated with readability, visibility, and intelligibility (Lefebvre, 1991). These elements, which form the framework of the spatial perception, are effective in making sense of the space and thus establishing a relationship with the user. On the other hand, the interrelation of the space with its user resides within the user perceptions. Design, which is an abstract and conceptual departure, becomes a tangible existence that can be experienced and engaged with through the user sensations. Instead of having a rigid and still existence, in the context of formation of space architecture is an alive compound within the user urges and derived perceptually through both with the user and the designer (Schwarzer and Schmarsow, 1991). Furthermore, the designed space as a product can be sufficient as long as it can be perceived. The object is the one that can be received in the senses of sensuality with the help of perceptions (Heidegger, 2007). In this context, it is plausible to consider all the things that space incorporates within as, in a way, objects. With the combination of design, form, material and the subject-object interaction, there will be a concept mechanics that nothing can prevent (Heidegger, 2007). The forementioned Lefebvre's spatial theory can be seen as a way of making sensible space exist through necessitating its creator or in other words designer to address the space and the user within. The lived and perceived space associates an abstract activity-surreal space and is directly related to the human being and his or her spatial experiences. The designed space, on the other hand, by itself alone evokes the concept of the physical formation of space.

Tracing back to the argument towards space to spatial, acquiring an immersive experience might have an ambiguity. According to Arnheim (1977), it is apparent that to tackle with architecture, one must employ on both the building that seen as a total object within the space through mind and the building experienced through people's actions as events. Spaces that appeal to a single sense will not be sufficient to reinforce the perception of space in the individual. However, this approach has dominated for a long time due to the predominance of the sense of vision. Sensory aspects were taken interest from natural sciences while philosophers worked on interpretation of perceived impressions on psychological level that lead research in that time period towards optical reception studies which effected art history and theory (Schützeichel 2013). According to Ionescu (2016), visual corresponds the affective experience which belongs to body, not to the autonomous concept and the body is the essential aspect of the architectural design. Indeed, the body is the constitute of space entirely; the movement, the sensations, the emotions all involved within the perception. With the light of apriori notions of cognition and the concepts of teleological spirit of Hegel, perceptual studies transformed from the values of domain and world of ideas to world of facts and reality (Schwarzer and Schmarsow, 1991). It can be suggested that what is seen and experienced within the sensations throughout the perception process bears the knowledge of the outer world. Bergson (1896) argues that perception develops under cultural psychological influences and that the personal imagination world is formed around these factors. Rather than directly connotating inferences, images are perceived as singular and by their own in which the viewer affected by the internal structure of their representations (Ionescu, 2016). The image enables the individual to feel belonging to the space. The emotional bond that the human establishes with the space is the result of image and notion and that is the process ones more which is differentiates the formative space with perceptual space.

3. INTERRELATIONS OF MEMORY, COLLECTIVE MEMORY AND SPACE

Since the perception process of the space takes place in one's mind through cognitive processes, the formation of space entails a participant or user whereas the unity of spatial perception recalls mindset and memory. The memory that allows spatial experience creates the spirit of belonging and space by associating the user within the spatial experience emerged. In broader scope of the interrelation of user and memory, the society in which users constitutes the social space phenomenon, along with the social space they constitute memory as well. According to Forty (2002), rather than focusing on the consciously made monuments, modern architecture issues the perceptual aspects as the inseparable component of the experience of outer world or, in other words, architectural structures and the most salient fact regarding this admiration is the normativity that employs on the cognitive operations of memory within the city. This section discusses the phenomenon of mind and memory under three fallowing parts as: first, the definitions of memory, social, and collective memory, second the interrelations of the subject of perception or the image and space, and third the connotations of these cognitive processes on the formation of space.

According to Sternberg and Sternberg (2011), Tulving and Craik defines the memory as the recalling the former experiences in order to utilize them today and Bjorklund, Schneider, Hernandez, Blasi and Crowder suggest that memory is a process in which dynamic processes as storing, retaining, and retrieving takes place within the limits of past experience. Sternberg and Sternberg (2001) identify the memory processes as encoding which converts data gained by senses to cognitive prospect; storage as the stock of encoded data; retrieval as the utilization of the stocked data within the memory. On the other hand, Halbwachs (1992) indicates that collective memory nourishes from the people's compatible body and each people belongs within a group of society accumulates the phenomenon through the cognitive process of remembering. Furthermore, collective memory embodies urban life through the people within the same urban context who correspond the same norms in terms of representations and prospects regarding the city, nourishes moral principles, assigns their connections, and reconciles their memories that belongs past (Belanger, 2002). Memory establishes its relationship with space through recall and memory. Memory, which gives the individual the ability to remember, is where the learned and acquired information is recalled. Due to the dynamism of time, there is no stasis of the individual's memory as well. A different and new experience that is remembered as the resulting memory is actually a past experience and therefore it is not possible to talk about the stability and permanence of memory (Yılmaz, 2011). The retrospective illusion that we hold tightly, even though with the memories we may choose to forget, seems more vivid and intriguing than present precisely from the younger periods of our lifetime (Halbwachs, 1992). Thus, new image and perception are overshadowed by the past experience. Perhaps we are not creating new memories; but we recreate the former ones within a new context recursively. Accordingly, another issue that can be considered as an important variable in the interrelationship of memory and space can be defined as the evaluation of the space as a living concept in the context of a social environment. It may be possible for the space and its components to cohabit and transform the social environment along with their existence. Furthermore, the way of existence and purposes of the space not only differentiate the user experience process but also lead to differentiations in memory. At the variable interplay of alive thing and the related object in fact is a requirement in terms of perception which emerges within the conscious state of mind (Bergson, 1896). All kinds of perception involve memories entirely and through the perception process, sensed information interweaves with the user's existing experience in a way that it suppresses the sensed information which was the initial perception and what residues at that point is simply an indicator for user to remember his or her own antecedent images (Bergson, 1896). In other words, the mind chooses what to experience, neither the subject of the perception nor the space itself. Is the perception can actually be an illusion? Sure enough that what is perceived and what is received cannot be completely different than each other but how much of the initial perception can penetrate into mind? Perhaps the answer goes back to beginning of the discussion, the processes which leads and forms the perception of each individual; it remains within the phenomena of self-conscious.

On the other hand it can be suggested that collective memory is developed by referencing and focusing on a social environment. According to Halbwachs (1992), collective memory is a concept that is structured socially instead of being given and since the conceptions regarding the past are under the influence of the mental images which are utilized to tackle with the current issues, it also arises as the regeneration of past within the limits of to-day. The social environment also creates a sense of social space. The content of this social space can include the elements of the social environment. Social space is neither a phenomenon apart from other things, nor a product among other products: on the contrary, it contains the things produced and the coexistence of these produced and the relations of their simultaneity, their order and disorder (Lefebvre, 1991). According to Yılmaz (2011), Casey stated that not only collective remembering but also forgetting played an important role in the formation of social memory. Because the perception of the user who coexist with the city and correlates with it as a constant state of motion; the city transforms through this movement and vitality recurrently. The user who engages and interacts with the city utilizes the history, culture, and the social relations of it. Therefore, it is possible to suggest that the social memory emerged through those associations concerns and sets a commonality for multiple disciplines all together. At this point, what is meant by the social is the collective memory. Within the collective memory, the foundation of sociological theory of memory resides and the formation of memory always emerges according to social codes (Halbwachs, 1992).

Architectural structures that constitute the structure of the city and the scope of social relations can be effective in the context of urban memory by forming the perception process of the user regarding the city. Consequently, in every case the user has to correlate and perform together with the city as a total product. As long as the architecture structures will be a component of the city, the user will be an inseparable part of that equation. On condition that interplay, only then one can argue with the idea of urban memory. Because of its social basis, space and memory are suitable for both transformation and manipulation: on the basis of formation, it can correspond to the issues that may concern the society within the users interests and knowledge. Likewise, the concept of participatory social memory may be utilized to transform the users within the city intentionally as well. Seeing objects through ourselves is the way how they are seen from the others whereas seeing objects apart from self--respective is not the unity of the object and ourselves but a perspective stance from the others (Halbwachs, 1992). With these insights, one must first understand the aspects within the formative space, then through internalizing with it, the spatial experience needs to be re-evaluated.

4. COLLECTIVE MEMORY IN DIGITAL AGE

According to Yılmaz (2011) Foucault indicates that "The way the past is represented determines what and how to remember it". On the precise opposite notion memory is a condition of vitality that nourished by the active life of society, a lasting progress in which the operations of remembering and forgetting and open to transformation recursively whereas history employs on reconstitution which is unfinished and troubled (Nora, 1989). Furthermore according to Nora (1989), memory is a consistent phenomenon in which employs on to relate ourselves within the present, enchanted and an affective notion whereas history is a mere image

Figure 1: Engram / Synthetic Memory
Source: https://refikanadol.com/works/melting-memories/ [9 January 2023]

of the past that entails criticism and analysis. With respect to counterplay of the memory and history, the recollection notion of mental process is examined through the public artwork installation of Refik Anadol named Melting Memories. The installation exhibited at Pilevneli Gallery in İstanbul in 2018.

It is possible to say that Anadol intends to represent mental data of the memories on a plain canvas in an intelligible manner. In a way, the artwork decodes the mapped neurological information to be experienced as visual and auditory language. Through the transformation of the collected data sets acquired from EEG which monitors the brain activities

Figure 2: Diagram of Engram Data Sculpture
Source: https://refikanadol.com/works/melting-memories/ [9 January 2023]

and operations within the Nueuroscape Laboratory at the University of California, San Francisco, the project proposes new insights on the interconnections of different disciplines (Anadol, 2018).

At Figure 1, one of the most popular piece of the exhibition shown. With a media wall and custom software (Figure 2, Figure 3), presented work represents a visualized mapped data initially belongs to the human memory and hence to EEG weaves. The way that EEG channels manipulated to represent visual experience also involves different aspects of memory such as long-term and short-term. Overall, the installation captures and presents an exact visual model of the human brain memory processes. Anadol (2018) suggests that with the terminology used in the title as Melting Memories, paradigm of new space in which artificial intelligence plays an irrefusable part, the disagreement on the utilization of artificial intelligence finds a common ground through an intimate and individual attributes of it. Besides than the promising features

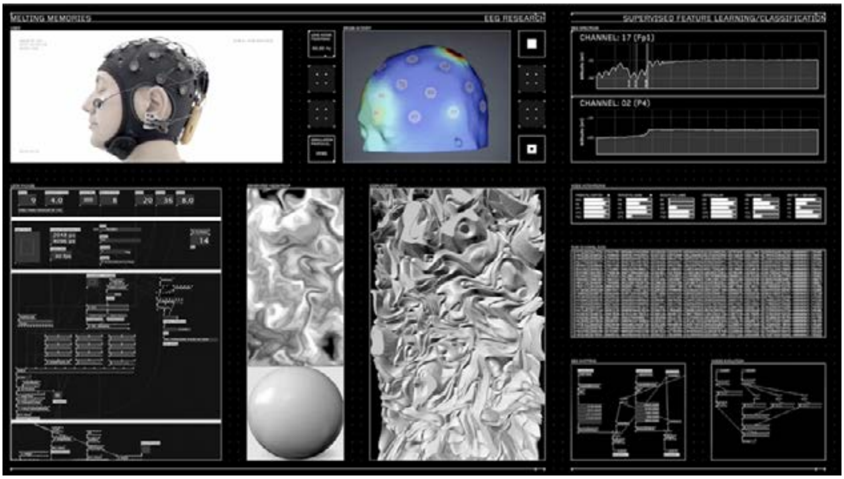

Figure 3: Diagram of Data Collection of EEG Maps and Generations
Source: https://refikanadol.com/works/melting-memories/ [9 January 2023]

on the transformation of two different languages in tangible and representative way, it can be suggested that most salient contribution of this work is the idea of permanence of the memory, thus history. Tracing back to the motivation or the intuition that derives individuals to transform the given experience within their memories and past experiences, issued work of Anadol presents another prospect for storing the retrospective memories that people keen to hold on tight. Although this piece of art focuses on the individual's cognitive memory maps, since the accumulation of collective memory rely on the faculties of individuals, it is also applicable to massive recollections of the memory.

5. CONCLUSION

Throughout this paper the issues regarding the formation of space, spatial paradigms, spatial perception and experience, memory and space interrelations are discussed. The interplay between the memory and perception are analyzed. Departing from the prospect that tackles with the interpretation of perception, study unveils the processes that leads to this transformation. Consequently, the processes as the cognition, memory, collective memory are probed. In order to understand the connotations of the memory, Refik Anadol's data sculpture titled as Melting Memories is examined.

The memory processes of remembering and recollection have become substantial basis for interchanging and providing a tangible space for images and their conveyed meanings whereas recall does not indicate memory in psychological sense but resides in the capability in the recollection of former experiences in order to relate them within a new facultative context (Boyer, 1994). Moreover Boyer (1994) suggests that the memory images can be utilized to create an intuitive a new image for future through recalling, re-evaluating, and recontextualizing within the collective memory. The interconnections of the phenomenon of memory both preserves the ability to restore and recreate within the city and individual. It is out of the question to talk about the stability of space and related concepts in the universe, which is dynamic and changeable by its nature, but it can be mentioned about the formation of social space with a social memory fed by the continuity of change. Social space is the result of a sequence and a set of operations, and for this reason it should not be reduced to the status of a simple object (Lefebvre, 1991). The association of space with the individual, the individual with memory and imagination, and thus the formation of social memory as a result of these can be seen as a collective process. For the formation of these values, whose coexistence can be mentioned as being dependent on each other, it can be said that one cannot exist without the other. Misztal (2003) asserts that according to Schwartz one of the most essential dissertation of Durkheim is the interconnectivity of the constant and fluxional state of the past and memory in any sense memory cannot be separated within its social extent in terms of language and the representative norms of the society. According to Misztal (2003) Durkheim asserts that a connection and permanence between now and past always required and represented through societies and the identity of inhabitants of the city enables the collective memory to seen as an extension of social existence. On the other hand, the inferences of the case study of Refik Anadol's Melting Memories asserts that the admiration and longing for past experiences neither have to be confined to the past nor the future has to be dominated by the past. Still, no one can argue with the fact that future experiences will be affected from the past in one way or another, but the crucial point is that if there is a chance to store the most precious memories or the moments of our lifetime, even with a different dialectic, perhaps we will let them go more easily so that future will not be tied or formalized only within the limits of the memory.

It is possible to argue that memories are generic yet specific, they can be accumulated through shared values, experiences, history within the same context whereas they can be precisely specific through being one of a kind, unique to a single human being. The ambiguity of the phenomena reverberates in all counterparts of the notion. Nevertheless, it is quite concrete that memory is a permeant constitute of cognitive processes. Within the city, individuals hence the memory shapes the city whereas the city shapes the inhabitants. Memory is a constant in the city as vital, affective, a recursive cycle.

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COMPARING DESIGN PRODUCTIVITY REALIZED IN THE PHYSICAL MODEL AND VIRTUAL REALITY

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ABSTRACT:

Throughout the design process, the designer shifts between various mediums and scales. The design activity takes place in the representative medium that best suits the design problem at hand. In this sense, physical models are very important in the early stages of design, especially in terms of triggering three-dimensional thinking and representing 'inner' thought. As a matter of fact, we observe that virtual reality, which has recently started to be integrated into the design world, also contributes to the designer in terms of representing three-dimensional thinking and shapes the thought. In the literature, the contributions of physical models and digital models to the design process and product have been investigated. However, similar research area is limited in terms of comparing and analysing productivity for physical model and virtual reality. Investigating productivity in the design process by comparing it with the physical models by using an innovative, technological medium in the design process constitutes the problem defined by the study. In the study, it is aimed to decode the productivity of the early stages of the design process. The paper uses the Linkography method, which was introduced to the literature by Goldschmidt (1990), for the quantitative measurement and analysis of productivity. The paper uses protocol analysis to obtain information and analyse the data. To apply the Linkography method more comfortably, the paper uses the think-aloud method. In the protocol analysis, a doctoral student with a bachelor's degree in architecture was studied. The participant was expected to propose a proposal for the architectural design problem, first with a physical model and then with a virtual reality environment. With the application of the thinking aloud method, it was observed what the participant thought and how she reflected her thoughts during the design process. The results of the study shows that, the productivity result in the physical model is higher than the results in the virtual reality environment. These values are very close to each other; however it can still be said that design development with physical model gives a more productive process. Besides, since the designer observes the topography, surrounding buildings and their relations with them in an integrated manner while working with a physical model, a more intricate network in Linkography map is observed. These differences suggest that the differences in design environments affect the design process and design thinking. The medium used in the design processes has a direct impact on the design process and productivity.

Keywords: Design Cognition, Physical Model, Virtual Reality, Productivity, Linkography, Protocol Analysis

1. INTRODUCTION

Cognition in design provides information about the process within design and tries to understand how design thinking occurs. The importance of cognition in design depends on the designers' understanding of how they express or act on a particular design problem and the appropriate measurement techniques.

One of the basic constructs in the field of cognition in design, put forward by Schön (1987), is that the design has a reflective process of rather than has a linear process. According to Schön, when designers sketch something instead of just thinking about it, they can generate more information about previous design moves in the design process to record the 'inner thought' and reduce their mental load. Using an external memory tool, it allows the designer to switch between design steps. The use of an external tool is not restricted to mere recording of thought. There are also various ways of recording thought using different representational tools. However, each external tool offers different possibilities to the designer, so it is the process of the design process depending on the different representation media. For example, the study of Salman et al. (2014) observed that the use of CAD software by participants changes the process of design. It has been observed that students who use CAD software during the design process pass from an idea more slowly than a motion sketch, spend less time analysing the design problem, and focus on detailing, which consumes most of their time.

Throughout the design process, the designer shifts between various mediums and scales. The situation seen in Dorta et al.'s study (2016) also shows the change in the design environment that the designer uses to reveal his thinking. In the 9-week study, the participants used 2D and 3D sketches intensively in the early stages of the design to convey and shape their ideas, and after the 5th week, the sketches were replaced by digital modelling. In the last weeks, physical models and animations have been used. This study shows us that the design activity takes place in the representational medium that best suits the design question at hand.

In another study by Heylighen and Nijs (2014), it is mentioned that a designer who lost his sight later developed a model production technique instead of using conventional techniques to convey the design idea, but the model making technique in question also changes the designer's thinking. Therefore, investigating the relationship between the design environment and design thinking is very important in the field of cognition in design.

Although we observe that virtual reality, which has recently started to be integrated into the design world, also contributes to the designer in terms of representing three-dimensional thinking and shapes the thought, studies examining virtual reality and the design process are in the minority in the literature. For example, it has been investigated how the use of physical models and the use of virtual reality affect creativity in the design process. While it has been observed that the use of physical models increases creativity in the early stages of design, it has been observed that virtual reality supports creativity in the later stages of design (Sachanowicz, 2019; Abdelhameed, 2017). However, the way in which the concept of creativity is handled may differ between studies. In addition, productivity in the design process may not be directly related to creativity. Therefore, the aim of the study is to investigate the use of innovative, technological medium in the design process, and to compare them with the physical models, which are seen as traditional design medium, on the basis of their productivity in the design process. The study predicts that the productivity values in the design processes that take place in two different design environments are close to each other. However, the study expects that that forelinks/backlinks ratio will be at a higher rate in the

VR environment than physical model since the designer can easily shifts between different scales.

The study made a comparison of the design process through physical model and virtual reality modelling, when trying to reduce the effect of the variable depending on the designer and the defined architectural design problem. Because the study was based on a comparison of design processes in different representational settings, two different experiments were conducted with the same participant. The data obtained from the experiments were coded by the Linkography method introduced to the literature by Goldschimdt (1990). In the next section, information about the method is given. After the method, the experiments is presented. After the explanation of the experiments, the Linkography method was explained, and the analysis of the studies was carried out. Later the analyses, the evaluation and discussion section and finally the conclusion section are included.

2. METHOD

It is seen that protocol analysis is mostly used as a method in studies in the field of cognition in design. Protocol analysis are considered to be directly accessible to the designer's cognitive processes, unlike other empirical study methods (Hay et.al. 2017). There are also various sub-methods in protocol analysis. The most widely used is the think-aloud method (Ericsson & Simon, 1993). In the thinking aloud method, the participant's actions and thoughts during the design process should be verbally expressed and their actions should be recorded. After the recorded statements and actions are examined, necessary analysis are carried out. As another method, the retrospective method is used. In line with this method, the participants try to explain what they thought and what they did while developing the design after the design processes. However, in this method, there is a risk of purposefully deforming their thoughts, as the participants will not be able to fully remember their past actions.

In the literature, one of the points criticized in the thinking aloud method is that it is thought to affect the perception of the designer in the process (Suwa & Tversky, 1997). In contrast, according to Ericson and Simon, the pre-made think-aloud exercises revealed that thinking-aloud did not cause major changes on the process (Ericson and Simon, 1993, as cited in Özbaki, 2016).

In the literature, the design processes carried out in various design mediums have been compared with the Linkograf method on productivity. While a comparison was made over physical model and digital modelling in Özbaki›s study (2016), a triple comparison of sketch, physical model and digital modelling was made in Gürsoy's master's thesis (2010). In the studies, they defined the design problems to the designer and asked them to solve these problems through various mediums. For example, the program of the design problem given in both studies and the location selection have similar features. In this way, they investigated the effects of the design medium by reducing the effect of the variable depending on the designer and the defined architectural design problem. In both studies, protocol analysis was performed and the thinking aloud method was preferred. The data obtained from the protocol analysis were analysed by the Linkography method.

As a result, in the study, similar to the studies in the literature, it was found appropriate to use the think-aloud method in protocol analysis. In addition, it was found appropriate to use the Linkography method in the study. It is therefore important to observe the design process as clearly as possible. In this way, it is easier to detect links and design moves in the design process compared to other sub-methods. Elaboration on the Linkography method will be made in Chapter 4.

3. PROTOCOL ANALYSIS

In the protocol analysis, the study was carried out in two different representation mediums, and the designer was expected to find a solution to the determined design problem first with the physical model, and then to develop the other defined design problem on a virtual reality environment. While designing problems, well-defined problem definitions were given rather than ill-defined problems defined by Herbert (1973). The reason for this is to try to minimize the variation of the design process that will emerge according to the background knowledge of the designer. Defining the problem definitions as close to each other as possible for both design problems can be explained as reducing the variability of the design problem and highlighting the effect of the representational environment in which the design takes place. Another important element while creating the architectural design is the environmental data related to the land. In both problem definitions, elements such as similar topography, sizes, relationship with surrounding buildings and main roads have been tried to be defined similarly. When defining both design problems, it is important that they are not identical with each other, but differ from each other with minor changes, because the participant's thoughts in the first design problem should not reflect the process in the second design problem. In the protocol analysis, productivity in the design process was tried to be measured through the conceptual design process. The participant is a doctorate student at İstanbul Technical University, in Architectural Design Computing program. While determining the participant profile, the aim of making a choice for the participant's physical and digital modelling levels to be close to each other was effective. The participant was expected to make a suggestion for the architectural design problem, which was first given in the physical model environment and then in the virtual reality environment, three days apart.

3.1. Design study with a physical model (PM)

In the physical model (PM) study, the participant worked on the physical model and his actions were recorded in order to be able to analyse it later. For this, a camera was placed in the work area where the physical model was made. In addition, since the think-aloud method will be applied, a sound recording was also taken as well as the video recording.

For the implementation of PM, a 1/500 scale model was studied. The reason why the model is 1/500 scaled is that it is thought that it is appropriate to carry out the analyses made on the early stages of the design on 1/500 model as an architectural expression technique. For the physical model study, a physical model including surrounding buildings, roads and isohips was given to the participant. In order to make her own model, a photoblock with a thickness of 2 millimetres, scissors, a utility knife, glue, and ruler were provided. Figure 1 shows the Physical Model working environment.

Figure 1: Physical model study environment.

The land chosen for the physical model is located in Sancaktepe, Istanbul. Consideration was given to choosing a field similar to the initial design study. The design problem is housing units. It was requested that the housing units be differentiated according to their various usage needs and sizes, and when creating the program, the participant is expected to create 4 3+1 flat types, 6 2+1 flat types and 4 1+1 flat types. In addition to this, it includes a design problem that can serve the residences jointly, but does not allow outside users, and is expected to serve 30 people. Figure 2 shows the design scenario for the physical model. A printout of the image in figure 2 was given to the participant.

Figure 2: Design scenario for physical model study.

There was no time limit for the participant to perform the physical model work. The design process ended when the participant found the design product he developed as “satisfactory”. The participant’s study took 22 minutes.

3.2. Design study through virtual reality (VR)

In the second design study developed using virtual reality (VR), the participant worked in a virtual reality environment. The actions of the participant were recorded in order to be able to analyze them later. In addition, her movements in the virtual reality environment were also recorded via screen recording.

Since VR was performed through virtual reality, virtual reality glasses and arms were given to the participant. Before the study, the participant was given training in order to experience working in the VR environment and to have foreknowledge about the tool. The training lasts around 150 minutes. The VR Sketch program developed by Sketch Up was used in the study carried out in the virtual reality environment. The reason for choosing this program is that it has an interface similar to Sketch Up, the commands are similar, and it is easy to work on architectural design, since the participant is familiar with the SketchUp interface. HTC Vive Pro was used as a virtual reality device (Figure 3). The model given in the virtual reality environment has the same land boundary size as the physical model and includes the same type of environmental data (environmental buildings, roads and contours) (Figure 4).

The land selected for virtual reality is located in Istanbul Sancaktepe. The design problem is the dormitory building for secondary school students. The room types in the dormitory building are classified as 4-person, 2-person and 1-person. The participant is expected to create 4 dormitory rooms for 4 people, 6 rooms for 2 people and 4 rooms for 1 person

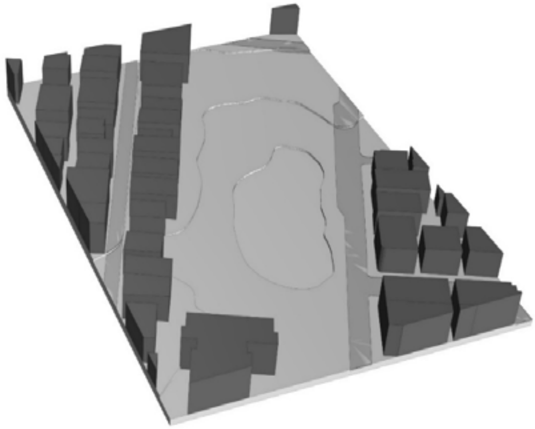

Figure 3 (left): Virtual reality study environment with HTC Vive Pro.
Figure 4 (right): 3D model provided to the participant for the virtual reality study.

(for 32 people in total). In addition to this, a design problem has been defined with a cafe that can serve to the dormitory building and is expected to be open to customers from outside and is expected to serve around 30 people. Figure 5 shows the constructed design scenario for virtual reality. A printout of the image in figure 5 was given to the participant.

There was no time limit for the participant to perform the virtual reality modelling. The design process ended when the participant found the design product he developed as "satisfactory". The participant's study took 73 minutes. Figure 6 shows a screenshot from the study, the participant notices the yellow mass is too close with the white mass (café) when she sees the formation from human scale.

Ortaokul öğrencileri için Yurt binası

Dormitory building for middle school students

A residential area that is expected to include social areas that students can use for secondary schools in the surrounding areas. The number of rooms varies according to preferences.

Dormitory Complex: 4 rooms for 4 people: 4*4=16

6 rooms for 2 people: 6*2=12

4 rooms for 1 person: 4*1=4

Total: 32 people

Cafe: A facility that can be used from outside and can serve approximately 30 people.

Figure 5: Design scenario for virtual reality study.

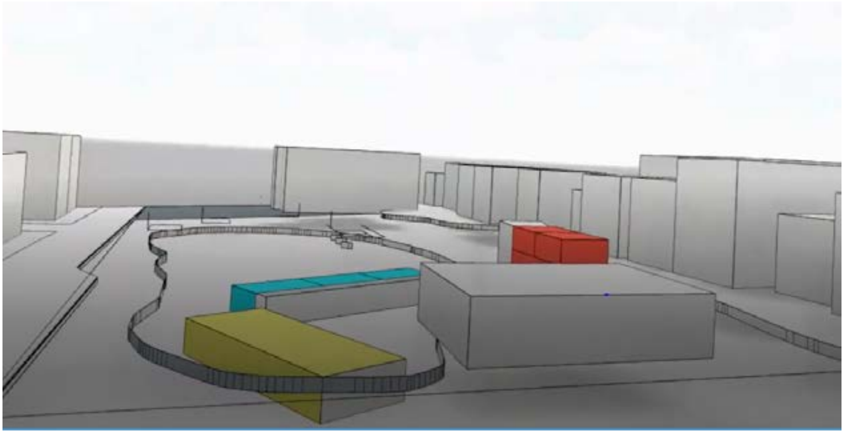

Figure 6: A screenshot from the VRSketch interface in the study.

4. LINKOGRAPHY ANALYSIS

Goldschmidt, G. (1990) introduced the Linkography method in her research on cognition and productivity in design. Linkography refers to the study of the connections and relationships between different design moves in the design process. According to Goldschmidt (1990), these connections can be used to measure design productivity as they allow designers to access and use relevant information and resources efficiently. Goldschmidt's work has had a significant impact in the field of design cognition as it helps to shed light on the cognitive processes underlying design productivity.

Developed by Goldschmidt in 1990 (Goldschimt, 1990), the Linkography method is a marking and analysis system that focuses on design moves in design processes and the links between these moves (Goldschmidt & Tatsa, 2005). The network structure emerges through the detection and visualization of design movements and connections in the design process. From a standpoint at this point, the design moves and connections need to be defined carefully for this study.

The term design moves refer to certain actions or decisions that designers make during the design process. In the light of the data collected by protocol analysis and thinking aloud method, the designer's thought and action patterns are divided into sub-parts. Each of these sub-parts can be defined as a design movement. These design movements can be related to each other in the design process or they can be discrete. The study of relationships between design moves is associated with the term link(s). Links are determined by the fact that the two design moves share a certain partnership.

Links are determined by whether the content of the two design movements has enough commonality to qualify that common ground as a link. Connections are divided into two. The first of these are backlinks, which depend on previous actions or thoughts. The other one is called forelinks and forms the basis of future moves and thoughts (Goldschmidt & Tatsa, 2015).

For design productivity; The number of design moves, connections and critical moves is important. According to Özbaki (2016), the Link index is used to measure the productivity of design and critical moves. Link index is the value obtained by dividing the number of links determined in the Linkography analysis by the number of design movements. A high value indicates that connections are made proportionally more frequently during the design process. Therefore, the Linkography graph will have a much more intricate network and will show that the design process is more productive. Goldschmidt (1992) defined 3 types of patterns in the Linkography graph, which she named Chunk, Web, and Sawtooth Track. However, these pattern definitions will not be included in this study.

5. EVALUATION AND DISCUSSION

In the study, design moves, links, Link Index, forelinks and backlinks will be examined in order to establish the productivity in the design process realized through physical models and virtual reality. Goldschmidt states that if the link index value is close to 2.0 in a Linkography, the connections between the moves and therefore the productivity are high, and if the index value is below 1.0, it is weak (Goldschmidt, 1990, as cited in Özbaki, 2016).

In the protocol analysis, a total of 18 design movements were detected during the design process in PM. Figure 7 shows the Linkography graphic created by the physical model process. There are 19 links between design moves. Therefore, it is seen that the Link index is 19/18, ie 1.05. Of the links, 6 are forelinks and 13 are backlinks.

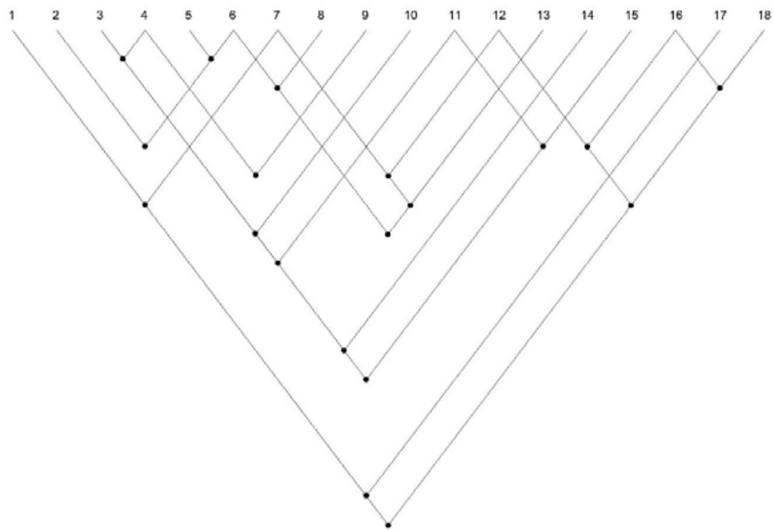

Figure 7: Linkography graph created by physical model study

When looking at the design process in the VR, a total of 19 design movements were identified. Figure 7 shows the Linkography graph created by the virtual reality process. There are 17 links between design movements. Therefore, it is seen that the Link index is 17/19, that is, 0.89. 3 of the links are forelinks, 13 are backlinks, and 1 is both forelink and backlink.

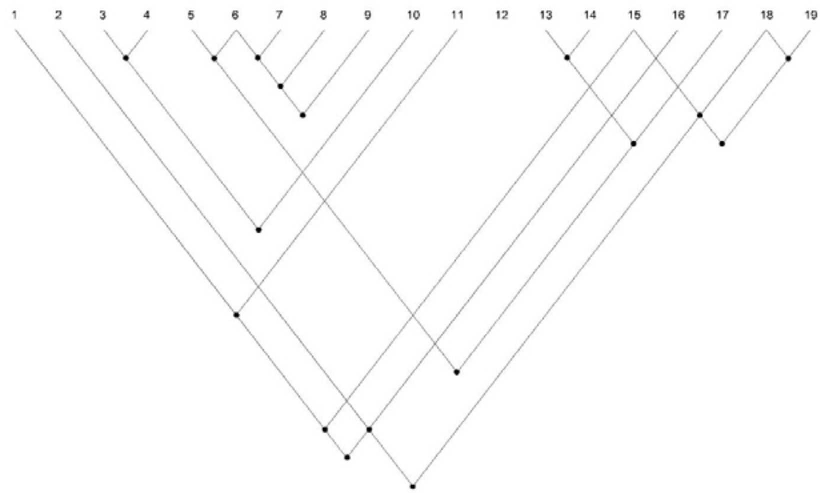

Figure 8: Linkography graph created by virtual reality study

When the link indexes obtained from two different representation environments are compared, it is seen that the result in the PM is higher than the result in the VR. These values are very close to each other, but it can still be said that design development with physical model gives a more productive process when viewed through the link index. If the link index value is below 1.0, it can be said that the design process carried out with virtual reality is weak, considering that, it is weak.

Looking at the Linkography graphics, it is observed that VR involve more connections that trigger each other sequentially. In the graph, it is observed that 5 single-hop connections (connecting with the move immediately after or before it), 1 double-hop and 2 three-hop connections are established in VR work; Although the number of connections in the whole design process is higher, it has been observed that 2 single-hop connections, 2 two-hop connections, and 0 three-hop connections are established in PM. Since these results may indicate that, depending on the problem the designer is currently dealing with while developing a design with VR, she can identify the problem in the problem she is interested in and changes her point of view, scale of the model and the information exposed by the model, therefore solve it within a few design moves. However, since the information exposed by the designer's perspective, scale and model in the PM process is not dynamic as in VR, it can make much larger leaps between design movements in the design process. In addition, a much more holistic process has emerged as the designer observes the topography, surrounding buildings and their relations with them in an integrated manner while working with a physical model. Looking at the Linkography graphics, a more intricate network map and a higher Link Index in the PM process confirm this.

The ratios of backlinks and forelinks to each other in the design processes developed in physical models and virtual reality environments were examined. The purpose of this calculation is whether the reflexive process inherent in the design has changed in various mediums. Therefore, the ratio of forelinks to backlinks can tell us how integrated the designer has handled the process. When the physical model process is examined, it is seen that 6 of the 19 connections are forward connections and 13 of them are backward connections. As a result, it can be said as 6/13, ie 0.46. When the design developed over virtual reality is examined, it is seen that there are 4 forward connections and 14 backward connections in total, so we can reach 0.28 from 4/14. What matters in forward link/back link analysis is not which of the values is higher, but their closeness to 1.0. The closer the resulting value is to 1.0, the more integrated the design process can be said to be.

It is thought that the difference between these two values is due to the effect of the design medium on the participant. The higher forward link/back link ratio in the PM indicates that the designer thinks more integrated in the PM process. However, in order to observe the similarity--difference in question, it may be useful to see if the same ratios can be obtained with more participants.

It is thought that design development on a physical model gives a more productive result than design development in a virtual reality environment, that during the design process, it is necessary to constantly stay at a certain distance from the model and the land, therefore, it is necessary to constantly review the environmental data. This brought along a more holistic approach in the early design stages, resulting in a higher forelink/backlink ratio of the designer.

Although the processes carried out in different design channels do not have a direct effect on the productivity of the design, there are various differences between them and the study wants to discuss these differences. For example, in the VR process, the participant started the design from the interior, while in the PM study, she tried to create appropriate masses by calculating the square meters suitable for the functions in the program. In this case, the bottom-up approach is preferred for the VR process, while the top-down approach is seen in the PM process. In addition, transitions were made between various scales throughout the VR process. The participant, who also experienced the depth from the human perspective in the VR environment, benefited from both the upper scale and the human scale while making various revisions. In the PM process, however, since the scale remained constant, she rather evaluated the geometric composition and the relations of the masses with each other.

6. CONCLUSION

In this study, which tries to measure design productivity in the early stages of design, the study observes that design development with physical model gives a higher productivity value than design development with virtual reality. It has been determined that the Link Index in the design process with a physical model is 1.05, while the Link Index in the design process using virtual reality is 0.89.

Looking at the Linkography graphics, it is observed that VR involve more connections that trigger each other sequentially. More holistic process has emerged as the designer observes the topography, surrounding buildings and their relations with them in an integrated manner while working with a physical model. Looking at the Linkography graphics, a more intricate network map and a higher Link Index in the PM process confirm this.

There are some overlaps and divergences between the results obtained with the hypothesis of the study. The data obtained in the study, which predicts that the productivity values in the design processes taking place in two different design environments are close to each other, show that design development with physical model gives a slightly more productive process than development with virtual reality. However, the hypothesis of the study, which predicts that forelinks/backlinks ratio will be at a higher rate in the VR environment than physical model, contradicts the results obtained.

According to the results obtained from the study, designs developed in two different mediums have differences in terms of productivity and forelink/backlink ratio as well as providing different approaches to the designer. As a result, the medium used in the design processes has a direct impact on the design process and productivity.

However, the study still contains some deficiencies. By expanding the scope of the study, working through the whole process of design may be more efficient to investigate the design process of virtual reality. In addition, the number of participants should be increased. The representational environments that the designer is accustomed to have had an impact on the work. In order to reduce this effect, work with different designer profiles can be carried out. In this way, the development of the design in two different representational environments can move away from being dependent on the designer's own competence. Finally, patterns such as Chunk, Web, Sawtooth Track, as well as design movements, links, Link index, back and forward link types used to establish productivity in the study can be looked at. In this way, more data can be used to analyse productivity.

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CAN AN UNREALISTIC LEVEL OF DETAIL BE ENOUGH TO FEEL IMMERSIVITY IN VIRTUAL REALITY

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ABSTRACT:

The latest trends in computer graphics show that developers, in pursuit of the perfect image, are increasingly creating graphics that are difficult for the user to perceive. The struggle for impressive graphics has begun to raise questions among users more and more often, as graphic characteristics are infinitely approaching the level of hyper-realism, which in turn causes the phenomenon of underrealism and broken immersion in the virtual space. In connection with this, the question arises - Is there sufficient abstraction of the virtual reality object and space that has the same effect on user immersion as graphically more complex variants?

This paper is mainly divided to three parts, in first part, before proceeding to the analysis of existing research and examples from various fields of computer graphics, a few necessary terms are explained at the beginning of the article. First of all, the differences between the feeling of immersion and the present by the user in virtual reality are determined, since the level of detail of the scene has a direct impact on the user's perception of the virtual space. The second necessary concept is the uncanny valley phenomenon. This phenomenon determines that the realism of the avatar graphics can produce a negative impression on the user. In this work, avatars are considered as components of virtual scenes; therefore, their detailing is important at the level of visualization of the surrounding spaces in virtual reality.

After introducing the necessary definitions, this article will discuss and analyze examples of different types of graphics of virtual scenes, such as architectural visualization, computer game graphics and animated movies. Each of these fields and industries in its own way affect the development and perception of computer graphics by the user, so it is important to pay attention to each one of them.

The last part of this paper will focus mainly on the methodology of a future experiment, which is intended to be used to complete the main objective – find the level of detail and abstraction of virtual reality objects sufficient to achieve the necessary user involvement and sense of presence in a given space.

It is important to note that research of a sufficient level of detail of virtual reality objects will solve several problems at the same time: it will help the creators of games and virtual environments to use hardware more efficiently and create less demanding products that will have the same impact on users as graphically more complex variants and will be more accessible to a wider group of users.

Keywords: Virtual reality, Level of detail, Immersivity, Virtual environment, Avatars, Complexity of Virtual Scenes

1. INTRODUCTION

Nowadays, modern technologies are becoming an important tool in our daily life. Outdated technologies are being actively replaced by modern versions, and users are beginning to prefer the virtual world to the real one. For the creators of virtual scenes, it is important not to forget about the balance when creating spaces on the border between reality and the virtual world. At the moment, technologies for creating 3D scenes can offer the user of virtual spaces graphics that are as close to reality as possible, which to some extent violates the natural perception of users (for example, the phenomenon of the uncanny valley). This violation can be expressed in any component of the virtual scene from the creation of textures to the underdeveloped geometry of the architecture, this may be enough for the user to lose the feeling of immersion in virtual reality.

Research objective

The objective of my research is to find the level of detail and abstraction of virtual reality objects sufficient to achieve the necessary user involvement and sense of presence in a given space.

2. DEFINING THEORETICAL TERMS AND BASIC CONNECTIONS OF THE SELECTED TOPIC

For the creator of any virtual scene, whether it is a cartoon, a standard movie or a computer game, it is important that the user experiences a sense of immersion and presence. Immersion has a special meaning in the context of virtual reality, because it is mainly because of immersion in virtual reality that the method of stereoscopy begins to work, which allows the user to see the depth and spatial arrangement of elements

Stereoscopy – Stereo image, stereoscopic image (from the Greek στερεός "volumetric, spatial") - an image that causes the illusion of volume, that is, a feeling of relief and expansion in depth due to the peculiarities of binocular vision.

2.1 Immersivity, present and difference between them

The concept of immersivity and present is very important for this study because there is a direct relationship between the detail of a virtual scene and the user's feeling of immersion in this scene. Many researches merge terms immersivity and present into one term of immersivity, which is not correct and it is very important to distinguish between the two terms.

Immersivity is the ability of a virtual reality system to allow the user to feel as if they are in another space. We are talking about sensory information that gives the brain the impression that the user is in another place: visual information, sound, tactile feedback etc. Immersion depends on the technical specifications of the equipment used. For example, the Oculus DK1 provides less immersion than the Oculus CV1 due to lower resolution, field of view and so on. If we assume that there is a perfect immersion in virtual reality, in this case the user should receive exactly the same sensory information as in the real world: the brain should not be able to distinguish virtual reality from the real one.

Present means how much the user is actually involved and feels inside the virtual world. Presence really takes into account the specifics of the VR experience: if the story is compelling, the user will be completely absorbed by it, if other avatars naturally interact with the user, the VR world will feel more real, if the interaction with the VR world is easy and natural, the level of presence will increase. Presence indicates how involved the user feels in the virtual reality experience and how much he perceives it as a real experience that he is living.

The terms *immersivity* and *present* are interconnected, immersion is important for ensuring presence. Immersion is a connected set of stimuli and present is the result of the user's concentration, enthusiasm for the ongoing scenario in VR using this set of stimuli. For example, if the world in VR was perfect, but made in the style of the 80s, the user cannot really experience it and the presence (present) is therefore destroyed. But on the other hand, the user can feel the sense of presence even without immersion. If the story itself is engaging, with well-developed characters, and engages the user who is in the environment long enough for their brain to get used to these graphics, the user will experience a sense of presence. An example of this would be fantasy worlds where users feel like unrealistic characters.

There are many interpretations of the terms *immersivity* and presence, in some sources these terms are distinguished, but at the same time the definitions are mixed, but the *main idea is this*:

Immersion means how high-quality sensory information is in the VR scene, presence is how much the user feels like they are in virtual world. Understanding the differences between immersivity and present is very important for further creating scenes in virtual reality. VR developers who know the difference between the two terms can use this information as a tool to create special characteristics of virtual reality scenes.

It is important to note that the level of detail in a space has an important impact on both, the immersivity and the present of a virtual space. When creating a 3D scene, developers create a certain style of space, which affects the present and user involvement. All of this corresponds to the purpose of this space, and at the same time, the space is created with a certain level of detail, visual sensory information, which has a direct impact on the immersivity of the virtual scene.

2.2 Connection between immersion into the virtual environment and five senses

Immersive virtual reality is a representation of an artificial environment which replaces the real environment in a convincing way for users using sensory information. Sensory system is a set of peripheral and central structures of the nervous system responsible for the perception of signals with various modalities from the external or internal environment. The most well-known sensory systems are sight, hearing, touch, taste and smell.

Currently, only 2 out of those 5 senses are used in the development of immersive VR technologies – sight and hearing. The user sees, hears and, in some rare cases, even feels the virtuality.

Each of the senses has a special influence on the user's feeling of immersion. The amount of detailing of the geometry and the overall processing of the scene affects the feeling of immersion through the visual sensory perception of the user of the virtual space.

2.3 Perception of the virtual reality scene

The user's perception of the image in the virtual environment remains the main factor in creating a sense of immersion in virtual reality. Sight is the most dominant of all our senses, providing up to 70 percent of the information humans perceive. Texture, lighting, geometry level of detail, animation – all this must be processed when creating a virtual environment in such a way that the integrity of the scene is not disturbed.

Parallel to the development of modern technologies, the graphic characteristics of games and movies are also developing. Developers, in pursuit of a perfect image, increasingly create graphics that are difficult for the user to perceive, and the level of detail becomes so high that it is necessary to work with it very carefully. All it takes is one incorrectly animated movement or poorly created texture and the sense of immersion in the scene disappears.

If the geometry goes too far in the complexity of the details, but, for example, the animation looks insufficiently developed, the immersion in the space and its perception is lost. In their work, "Game Graphics Beyond Realism: Then, Now and Tomorrow," the researchers compare VR immersion to a soap bubble. Even small imperfections, such as an incorrect shadow, can destroy the illusion of realism, the immersivity is lost and the imaginary bubble bursts.

In this case, the phenomenon of the "Uncanny Valley" can be cited as an example of how the pursuit of hyperrealism can have a negative effect on the user. It is a phenomenon based on the hypothesis that a robot or other object that looks or behaves similar to a human causes discomfort and aversion in human observers. In 1978, Japanese scientist Masahiro Mori conducted research in which he analyzed people's emotional reactions to the appearance of robots. At first, the results were predictable: the more human-like a robot is, the more likable it seems—but only up to a certain point. The most humanoid robots unexpectedly turned out to be unpleasant for humans due to small discrepancies from reality, which caused a feeling of discomfort and fear. The Uncanny Valley phenomenon suggests that as the virtual scene becomes more detailed, at some point a positive perception can drastically change to a negative one. (Wikipedia, 2023)

This phenomenon is also very important to consider when filling the virtual environment with avatars. Imitation of human presence in space is an important factor of immersion into a virtual environment. Both in the real and virtual world, presence of people helps us perceive space.

The presence of people in architectural visualizations has always been an integral part of understanding the scale, mood and purpose of an architectural composition. It can be stated that not only the correct use of technical and architectural characteristics, but also the presence of avatars is important for full immersion in the virtual environment and maintaining the sense of perception of space. Therefore, one of the important factors of the space to maintain the feeling of immersion is also a competent study of avatars and their animations. However, the question remains how complex the geometry of the avatars should be. Currently, there are many studies that prove that the user of the virtual environment can identify even with simple geometry and even shapes that are geometrically very basic can fulfill the role of avatars in the virtual space. This suggests that perhaps properly executed abstraction of objects and spaces in virtual reality could have the same impact on the user as graphically more complex variants.

3. EXAMPLES OF EXISTING RESEARCH

At the moment, there is a sufficient amount of research on the graphics of virtual spaces. Most of the research is based on the graphics of computer games. A number of studies by game developers claim that non-photorealistic images look more natural and are much easier for users to perceive than complex photorealistic images. Even with the most advanced graphics hardware available today, all the so-called photorealistic games simply lack true photorealism. The improvement in image quality over games from 10 years ago is impressive, but the illusion of photorealism can be broken by even small inconsistencies like a bad shadow, and thus the overall feeling of immersion in a virtual scene disappears. it was noted in the studies focusing on various levels of detail of avatars, that the participants in experiments in which they were given several levels of detail of the avatar to choose from, most often chose the middle option as the most attractive. It is important to note that in order to study the perception of a virtual scene, it is important to pay attention to studies based on different components of the scene.

3.1 Can We Identify with a Block? Identification with Non-anthropomorphic Avatars in Virtual Reality Games. (AYMERICH-FRANCH, 2012)

This study is not new but differs from most similar studies because it is based on user's identification with a non-anthropomorphic avatar rather than identification with a humanoid avatar. This study is important for the research of the level of detail of scenes, because at the minimum level of detail, avatars are precisely non-anthropomorphic forms (geometry). In this paper, the question is considered - is it possible to identify a user with non-anthropomorphic avatars. Identification in this study is the process by which a user assumes the identity, goals, and point of view of their avatar. The avatar does not have to be human-like and can be represented by any non-anthropomorphic creature or character, i.e. a virtual object, animal, etc. The developers created a virtual game whose participants were represented by non-anthropomorphic avatars. During this study, the participants demonstrated moderate to high levels of identification with their non-anthropomorphic avatar.

3.2 Game Graphics Beyond Realism: Then, Now, and Tomorrow (Masuch and Röber, 2004)

This paper discusses the use of graphic realism in computer games. Despite the fact that 19 years have passed since the writing of this article, the ideas of the author remain relevant to this day. The main idea of the author is that most computer game developers try to imitate the visual impression of reality as accurately as possible, but this realism extends only to a certain extent. In games, we want to be heroes with superior abilities, and therefore we can change the laws of physics to suit the needs of the story. Why not also break the laws of graphic realism to improve the visual experience? Modern game computer graphics are constantly evolving and approaching realism, but figuratively speaking, not a single game developed up to this time can truly be called realistic. While most computer game developers have focused on recreating the real world, some have focused on non-photorealistic rendering, mostly inspired by human drawing techniques.

Non-photorealistic rendering (NPR) techniques are important because of many factors: virtual scenes can be expressive and perceived by users at the level of complex realistic scenes, while giving the game its artistic look. A number of NPR research articles claim that non-photorealistic images appear more natural and are much easier to perceive than complex photorealistic images. Even with the power of computer graphics today, photorealistic games simply lack photorealism. The speed of development of computer graphics is amazing, but at the same time, at this stage of working with graphics, we are on an endless straight line of development, which may never reach a realistic level of graphics. Immersion is like a soap bubble: even small inconsistencies, such as the wrong shadow, will destroy the illusion of photorealism and thus the immersion and bubble will disappear. (Masuch and Röber, 2004)

Surprisingly, non-photorealism seems to be much more tolerable, since non-photorealism is by default accompanied by deviations and sketchiness. Consequently, the design and feel of the graphics feel pleasing. Only developers with big budgets can reach the level of realistic graphics, as it becomes more difficult and expensive to maintain. Gamers can get fed up of the complex graphics and look for something else. With the help of NPR techniques, it is possible to solve many issues that are still relevant today when creating computer graphics.

3.3 Perception of virtual characters (Zell, Zibrek and McDonnell, 2019)

This study covers technical and artistic aspects in the user's perception of virtual characters. The ideas of this work can serve as an additional set of tools for creating more convincing, but at the same time unrealistic characters in virtual scenes. This article also provides an overview of existing research on user perception of virtual characters. I have chosen the most interesting examples that it is important to pay attention to when creating avatars of different levels of detail.

Research example 1

In this example, the developers evaluated the attractiveness and realism of female body shapes, which were created as morphs between a realistic character and stylized versions in accordance with the design principles of major computer animation studios. Surprisingly, after the experiment, the most attractive characters turned out to be intermediate morphs, where 33% of morphs had the highest realism and attractiveness scores, and 66% of morphs were rated as equally attractive, but less realistic. In this study, the form is noted as one of the main parameters, the material and other parameters increase realism only in the case of realistic geometry. Strong inconsistencies in stylization between material and form negatively affect the appeal of the characters and make them unrealistic.

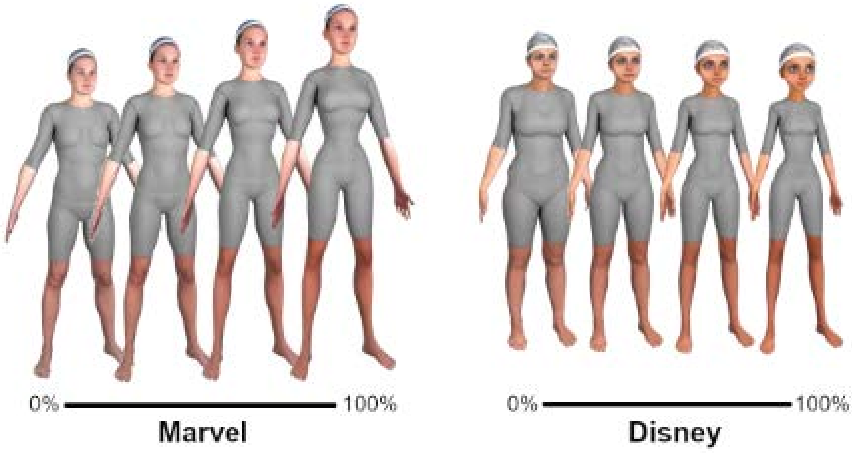

Figure 1: Visualization from research „Perception of virtual characters."

Research example 2

When testing the learning outcomes of a recorded lecture with slides supplemented by a small video in which a realistic instructor, a virtual avatar and a robot took part, the learning outcomes varied. Interestingly, students liked virtual avatars more than a real person or robot.

Research example 3

In several papers, research data experiments have confirmed that enlarging parts of the face reduces perceived attractiveness in characters. In addition, not only proportions, but also the location of parts of the face can influence negatively perceived attractiveness.

Research example 4

In addition to focusing on parameters that affect visual perception, it should also be taken into account that the user focuses on different parts of the body for different amounts of time. Using gaze tracking, this study determined that viewers were looking primarily at the head and upper

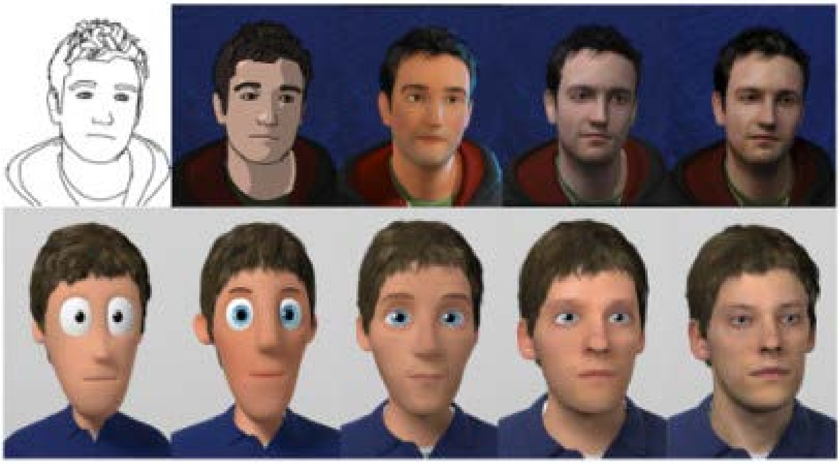

Figure 2: Visualization from research „Perception of virtual characters."

torso. Within the boundaries of the face, people look mainly into the eyes and mouth, but the number of fixations on the eyes prevails. A recent study showed that this is also true for virtual characters of different levels of stylization. On average, participants made eye contact 35% of the time, while in other regions of the body this figure varied from 0 to 10%. This may explain why VR designers consider the eyes to be the most important aspect to achieve realism. For example in Anime, the eyes are used to show the emotions of the character, while the nose is often preferred not to be drawn at all.

It is important to note that the movement or animation of virtual characters is an integral part of character design and determines success in creating a compelling character. People use non-verbal perceptual cues, such as movement and appearance, to form opinions or feelings about a character. Most social information is expressed through movement.

Research example 5

This study noted that when studying biological motion applied to virtual characters, shape and motion information interact to formulate a perceptual effect. Movement can also carry information about the emotions and personality of the mover. From this it follows that the movement, animation created for the avatar should correspond to its character and emphasize the general mood.

3.4 Building Information Modeling (BIM): Exploring Level of Development (LOD) in Construction Projects (Latiffi, Brahim, Mohd and Fathi, 2015)

It is the LOD system that most accurately indicates how, at different stages of work in construction, it is competent to use the amount of information sufficient for working on a project. Subtleties and details are not solved at the initial levels, and at the same time, general information is enough to gradually achieve the required level of detail of the project when advancing through construction project.

Building Information Modeling (BIM) means replacing a two--dimensional (2D) drawing as an architectural design with a three--dimensional (3D) model. BIM improves design efficiency, promotes an integrated design workflow, and reduces design errors. The BIM model, as it is created, is filled with a variety of elements, and each element can be represented with a different degree of elaboration - drawing details or the amount of attributive information presented in the properties. To grade elements by their richness of detail or attributes, the BIM community has adopted the LOD system. The level of detail, elaboration (LOD) allows to define and formulate the content of information models (BIM) at various design stages and during construction and operation. A level of detail is a graphical representation of an object that increases in complexity as the project progresses, often from a sketch to a detailed model. There are five

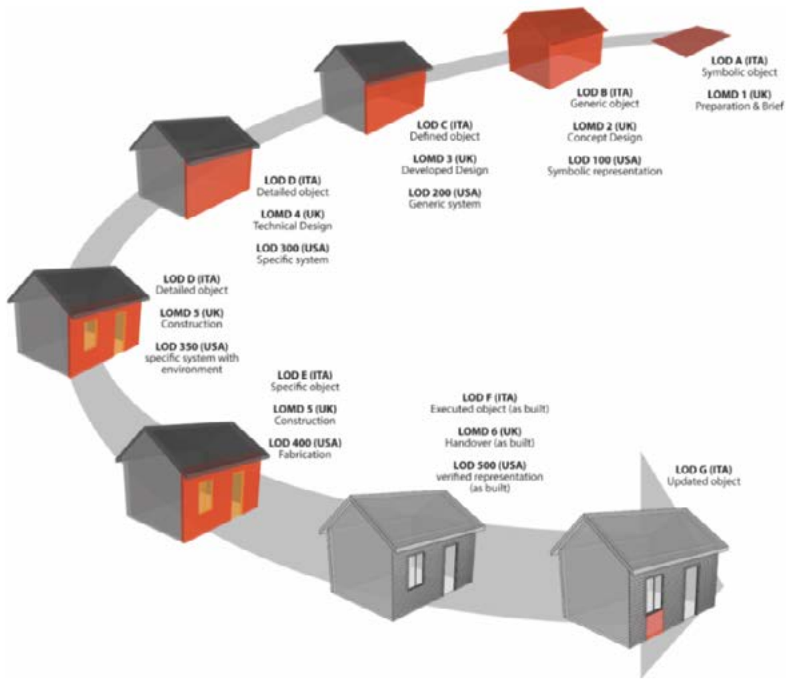

Figure 3: Visualization from research „„Building Information Modeling (BIM): Exploring Level of Development (LOD) in Construction Projects.

(currently 6 = LOD 350) LOD levels, which consist of LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500. The sequence of these levels starts with the concept of the object and ends with the execution.

4. EXISTING EXAMPLES OF 3D GRAPHICS

Examples of computer graphics can be cited from all sorts of areas that surround us. These can be visualization of architecture and interior design, computer games, animated films and much more. In each case, developers individually choose the level of scene detailing for the task.

The examples below show various examples of using different levels of graphics detail, some of them turned out to be too realistic and were not accepted by users.

4.1 Visualization of architecture and design of interiors in computer games

Speaking about the visualization of architecture, it is important to note that there are many computer architectural games whose developers did not focus on the detail and realism of graphics, but at the same time the level of detail used was sufficient to achieve success within users.

These are games like:
Calvino Noir by Dan Walters - Game created in black and white graphics, the developers of this game were inspired by the work of the 18th century architect Charles de Vailly.

Monument Valley by UsTwo - A minimalistic game with references to the architects of the 1970s. Architectural critic Alexandra Langre emphasized that architects can learn a lot from playing this game.

Minecraft - A sandbox game in which players build spaces using simple building blocks.

Hidden Folks - A game in which the user interacts with a monochrome but detailed environment.

Mirror's Edge Catalyst - A VR game where it is possible to pay attention to detaililng and at the same time stylizing spaces.

Cities: Skylines - A city building simulator game with well-designed graphics. In this game, user can develop entire areas of the city and transport systems.

Project Highrise - A game also based on simplified graphics in which players build a skyscraper starting from the first floor and then raise the building step by step.

The developers of all of the above games used stylized, unrealistic graphics, while respecting basic architectural norms. Despite the different level of detail and stylization, each of these games turned out to be graphically developed enough to feel the user's immersion in a virtual environment.

4.2 Examples of different levels of graphics detail in animated movies

Vivid examples from animated films include the latest film adaptation of The Lion King from 2019. and Sonic from 2020. These works indicate that hyperrealism can cause a negative perception in the user.

The first example is the movie Lion King

The creators of the film tried to reproduce the real life of wild animals as accurately as possible, which, on the contrary, created an impression of broken realism. By using hyperrealism, the creators lost all the main features that the heroes of the original film from 1994 had. After a few days of the release of the film, Russian illustrator Nikolay Mochkin, an artist from Yakutsk, decided to rework the characters as what they would have looked like if the creators had stuck to the original graphics and stylistics.

The second example is the animated film Sonic, the protagonist is a character from a series of video games originally published by SEGA.

The fan reaction to Sonic's new look was so strong that even after the release of the trailer, they started asking for the protagonist's appearance to be redesigned. Paramount and director Jeff Fowler went out

Figure 4: Comparison of original movie by Walt Disney Pictures and fan edit made by illustrator Nikolay Mochkin, source: internet

of their way to accommodate the fans and delayed the release by several months in order to completely redo Sonic and his face in all scenes of

Figure 5: Comparison of Sonic's original version presented in trailer and edited version made after complaints of viewers, source: internet

the film, bringing his appearance closer to the original, known from the games and animated films.

In contrast to the hyper-realistic graphics of modern cartoons, there are many graphically maximally simple animated films for adults, such as Ricky and Morty, Futurama, Family Guy, Cross Swords or South-park. For example, after a few minutes of watching Crossing Swords, the plot of the animated film begins to draw the viewer in and they forget that the story takes place among the toys.

5. METHODOLOGY OF EXPERIMENT

As it was outlined in the beginning of this paper, the objective of my research is to find the level of detail and abstraction of virtual reality objects sufficient to achieve the necessary user involvement and sense of presence in a given space. To complete this objective, I intend to use this exact methodology of performing an experiment:

I will create several versions of one virtual reality scene, which will differ only by its level of detail. The scene will contain geometry of environment and avatars. There will be a total of 5 versions of the scene.

The 1st level of scene detail (the lowest) will consist of environments and avatars, for the creation of which self-made 3D models and ready-made assets will be used.

The 2nd level of scene detailing will be slightly more detailed and will consist of environments and avatars, which will be created using self-made 3D models and ready-made assets.

The 3rd and 4th levels will be intermediate, located between the minimum and maximum levels of detail. Virtual scene objects for a given stage of the experiment will be created by hand using simplified realistic models from stage 5.

The 5th level of scene detail will consist of a realistic environment that I will model by hand and realistic avatars that will be purchased from the Asset Store. The animation needed for the avatars at the 1st and 2nd level of detail will be created manually, at the 3rd-5th stage it is planned to use animations from Mixamo with minor modifications.

Completed scene with all its versions will be transformed into virtual reality and will be given to participants of an experiment to walk through it and complete particular tasks to amplify the feeling of immersivity. Minimum number of participants will be 30. Basic requirements for participants is to be aged up to 35 years old and not suffering from cyber sickness (dizziness, headaches, nausea and vertigo induced by movement in virtual reality). Previous experience with VR is not necessary. The task of participants will be to identify version in which the level of detail is sufficient to maintain the feeling of immersion. To be able to analyze the data earned during the experiment and make conclusion, participants will be asked to fill in questionnaire after walking through the virtual environment. Based on the output data, I will define particular level of detail, which will have the same impact on user as graphically more complex variants.

6. EXPECTED OUTCOMES AND IMPACTS

The first expected result of the work is the combination of virtual environment assets. A certain part of the assets will be bought on the unity asset store and the remaining necessary part will be created by myself. These assets will be suitable for use in further research related to virtual environments.

The second expected result is the analysis of the obtained data. As part of this analysis, a sufficient level of detail of the scene will be determined, which in the future will help the creators of games and virtual environments to use hardware more efficiently and create less demanding products that will have the same impact on users as graphically more complex variants and will be more accessible to a wider group of users.

7. CONCLUSION

The first main purpose of this paper was to gather all the necessary data and information related to computer graphics of virtual scenes from different industries and to verify, that the main idea (the maximal level of detail isn't always needed) can be backed with already existing research.

To perform this research and verification was necessary in order to be able to move to the next stage which was defining the methodology of the future experiment, which will be used to achieve the main objective – find the level of detail and abstraction of virtual reality objects sufficient to achieve the necessary user involvement and sense of presence in a given space.

The issue of a sufficient level of detail is an important factor that all developers of 3D virtual spaces should consider. In order for the user, immersed in the virtual scene, to feel involved in the virtual environment and associate himself with the avatar, it is not necessary to use the maximum levels of scene detail. At the same time, hyperrealism can have the opposite effect on the user, which will destroy the user's sense of immersion in the virtual scene. In my future experiment, I plan to analyze 3D virtual scenes of various levels of detail.

The objective of this study will be to determine a sufficient level of detail of the virtual scene, the perception of which will have the same immersive effect on the user as more complex graphic variants. Determining a sufficient level of detail in a virtual scene will help virtual space developers create virtual scenes faster while maintaining the quality of their work. At the same time, these developments will be more accessible to most users, as they will not be heavy on the software as more realistic graphics options.

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VISUAL ATTENTION REAL TIME TRACKING OF 3D ARCHITECTURAL MODELS IN VIRTUAL REALITY

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ABSTRACT:

The use of virtual reality for architectural design assessment and presentation has been the topic of numerous discussions, research papers and tool development in the last three decades. Ranging from early uses of non consumer grade hardware all the way up to the modern affordable prosumer focused full body VR gear, each subsequent technology has brought advances in nearly all fields, including architectural design. This paper focuses on the developed tool "Aurela Sight ", its uses, potential and vectors of future development at the Aurela Laboratory of the Faculty of Architecture, Bialystok University of Technology, Poland. This software can be used to quantify user gaze on early stage furniture design, as a validation tool of the designer-consumer focal points relationship, as well as to be able to verify areas of low visibility for production related optimisation. At this point in time, the tool is able to gather user gaze data in real time using almost any modern VR headset, place it on an object, export it as an image file, and display the result on a duplicate model for later inspection. With the implementation of additional planes of user motion data gathering, the system is able to track and visualize player motion and their visual attention throughout the span of a given spatial task. Outputs are later analyzed in third party software, and presented to parties of interest for further development and analysis. Future development is planned in the introduction of multi-user scenarios, eye tracking, and ai driven in house analysis.

Keywords: virtual reality, CAAD, virtual architecture, design assessment

INTRODUCTION

Being able to quantify user gaze has been the topic of many research fields and studies for the past few decades, and has given much insight into the spatial perception of humans in certain case scenarios. Along with students from the Faculty of Architecture at the Bialystok University of Design a tool was created to gather user gaze data in real time, in virtual reality on almost any 3D model. This tool is called "Aurela Sight" and its primary focus is to lay out a foundation for future development of open source, easily reconfigurable tools [6] made in open source game engines such as Unreal Engine. A secondary mission of this tool is to provide useful insight into the way people look at objects in VR and to find possible patterns in the use of architectural spaces in the digital realm [1], [11].

The following paper focuses on the data collection and analysis aspect of the project, including the methods and tools used in the entirety. It should be noted that the Aurela Sight program is being currently developed and at this point is not yet ready for implementation in large scale research, as the gathered data needs labor intensive and expensive work to be done in the fields of increasing output quality, data capturing precision, implementation of advanced methods including retina eye tracking, AI based next step prediction algorithms and more. At this point in time, however, the tool is a useful experimentation device for use in computer aided architectural design at the faculty, and may see improvements in the upcoming months.

DATA COLLECTION PROCESS

Aurela Sight's data collection is focused primarily on the ability to capture head gaze data on specific objects of architectural design significance in the three dimensional space of Virtual Reality. Requiring a specifically designed and prepared 3D scene, researchers place a test subject into the prepared space with a HDM VR device and have the user perform a task that appropriately uses the tested object in the duration of the session [2]. After the task is completed, the user exits the program and finishes the trial, still unaware of the gathered information. For the user, this was merely a joyful task of looking at virtual architectural designs and prototype spaces in VR and was an ability to finally try out a modern HMD device. For the researchers, this was an insight into how the user looked at a specific object, and how the given task influenced that interaction.

The Aurela Sight program was conceptualized and written for a means of seamlessly and unknowingly capturing and recording real time gaze data onto specially prepared UV channels [3] for later export and evaluation in the process of which the following methodology was used to achieve it:

RENDER-TO-TARGET (R2T)

The R2T method involves rendering a scene to a texture, allowing for post-processing and manipulation before displaying it on the screen. In

Fig. 1 - A bedroom interior shown in the way a user would see the objects during the data collecting phase. Source - author.

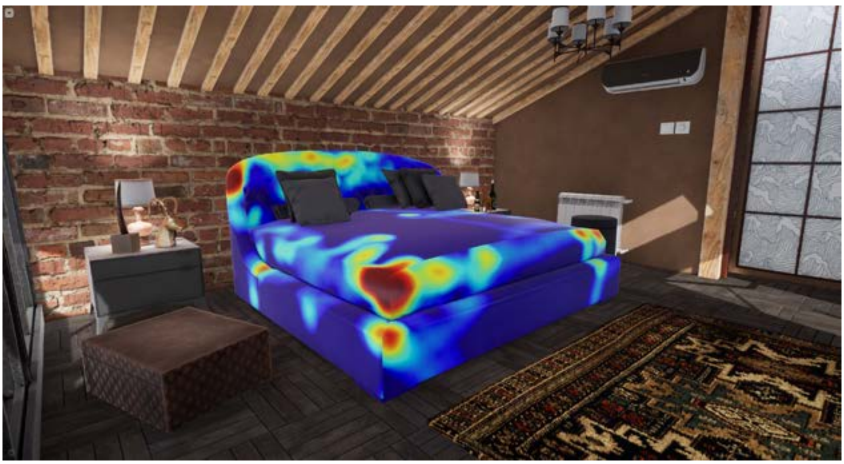


Fig. 2 - A 3D model of a bed with a temporary depiction of the gaze data in MatLab "Jet" color scheme, placed inside of a sample bedroom. Source - author.

“Aurela Sight,” this technique is utilized to generate a secondary render of the scene, which captures the gaze point within the virtual environment. In terms of secondary render, the difference between what the player sees and what the program is capturing is key, as it allows users to tweak what channels of information the program is gathering and displaying.

The program starts by calculating the user’s gaze direction based on the HMD device’s orientation, employing the device’s tracking data (i.e., rotation and position) and predefined field of view (FOV) settings [4]. Next, the program renders the scene to a texture, assigning each object a unique color. This color-coded representation of the scene serves as a reference to determine the object the user is gazing at. This step requires setting up a unique shader that outputs the unique color to the render target instead of the usual material properties. The gaze point is determined by sampling the pixel color at the calculated gaze direction intersection point within the color-coded texture[9]. By matching this color with the corresponding object, “Aurela Sight” identifies the object being gazed upon.

TEXTURE PAINTING IN INVISIBLE UV CHANNELS

The R2T method allows for object identification, but it doesn’t provide specific gaze point location information on the object. Texture painting in invisible UV channels is employed to address this limitation and obtain precise gaze location data. Each object in the scene is assigned an additional invisible UV channel, which is not visible to the user but can be accessed by the program. This UV channel contains a unique identifier for each surface point on the object.

To create this invisible UV channel, a unique texture is generated for each object. This texture contains an encoded representation of the UV coordinates, typically using the red and green channels for the U and V coordinates, respectively. The blue channel can be reserved for an object-specific ID, providing additional information about the object itself. During the gaze data collection process, the program samples the value of the invisible UV channel at the gaze point. This value corresponds to the precise UV coordinates on the object's surface. The UV coordinates obtained from the invisible UV channel are combined with the object's unique color obtained through the R2T method. This comprehensive dataset includes the object and the exact location being gazed upon, providing detailed gaze information for further analysis or application.

CUSTOM UV MAPPING

The importance of correctly mapped UVs of objects for Render-to-Target (R2T) data gathering cannot be understated. UV mapping is a crucial aspect of the rendering pipeline, as it defines how textures are projected onto 3D architectural models, ensuring that the texture information is displayed correctly on the surface of the object. In the context of gaze data collection using R2T, the precision and accuracy of the gathered data are highly dependent on the proper mapping of UVs for the architectural designs within the virtual environment. When using the R2T method for gaze data collection, each object in the scene is assigned a unique color, and a secondary render of the scene is generated. This color-coded representation is used to identify the object being gazed upon by the user. However, determining the specific location on the object's surface where the user is gazing requires precise UV mapping. This is because the UV coordinates correspond to the position on the texture, which, in turn, reflects the position on the object's surface.

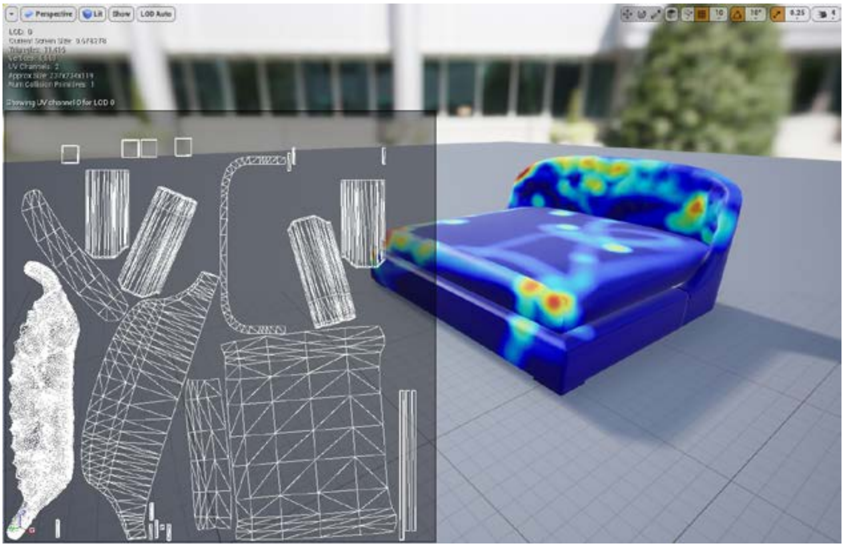


Fig. 3 - A 3D model of a bed with a temporary depiction of the gaze data in MatLab "Jet" color scheme. Source - author.

In the case of "Aurela Sight," an additional invisible UV channel is assigned to each architectural object to store a unique identifier for each surface point. If the UV mapping is incorrect or distorted, it may result in an inaccurate representation of the gaze point on the architecture's surface. This can lead to errors in the gaze data collection and compromise the system's overall accuracy and precision. Moreover, improper UV mapping can cause issues like texture stretching, overlapping, or distortion, which not only affects the appearance of objects in the virtual environment but also influences the gaze data's reliability. The invisible UV channel's purpose is to provide precise information about the gaze location on the object. If the UV mapping is not accurate, it becomes challenging to draw meaningful conclusions from the gathered gaze data or use it in applications that require high precision, such as research studies or gaze-based interactions. Users who would likely focus on key design features would be then falsely recorded as viewing random structures or meaningless spaces on facades and structural elements, instead of correctly placing their interest on contrasting shapes and architectural elements.

To ensure the accuracy and reliability of the gaze data gathered using the R2T method, it is imperative to have correctly mapped UVs for all objects in the scene. This can be achieved by using proper UV mapping techniques and tools during the 3D modeling and texturing process, taking care to avoid issues like overlapping, stretching, or distortion. By ensuring the correct UV mapping of objects, researchers and developers can harness the full potential of the R2T method for gaze data collection, enabling them to create more accurate, precise, and reliable gaze tracking systems for various applications and research purposes.

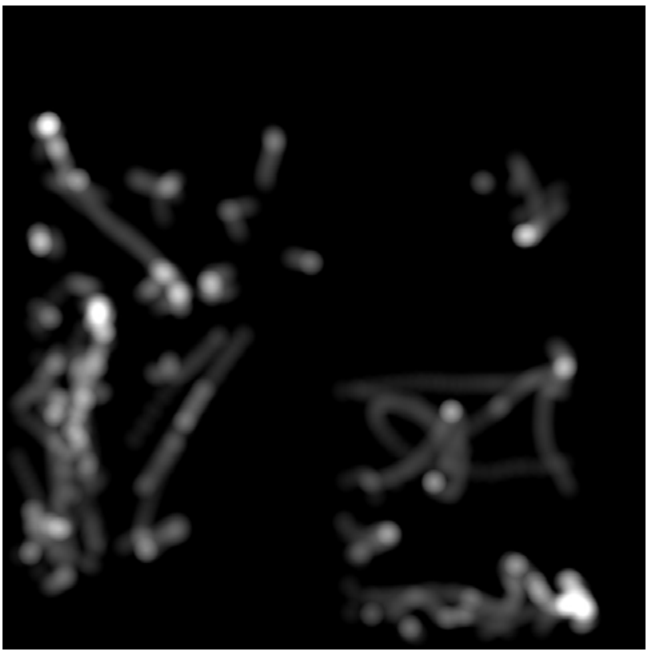


Fig. 4 - One of the test subjects gaze data recordings. Source - author

Recorded data is converted into a black and white EXR image texture, which represents where, how long, and how often a player looked at each specific region of an architectural model, as seen in the above image. Information is converted into single channel data due to the ease of further analysis and possible file complexity issues with multi channel data. This type of data is called a ground truth texture, and is often used with gaze tracking [13] in multiple other software tools and implementations around the world.

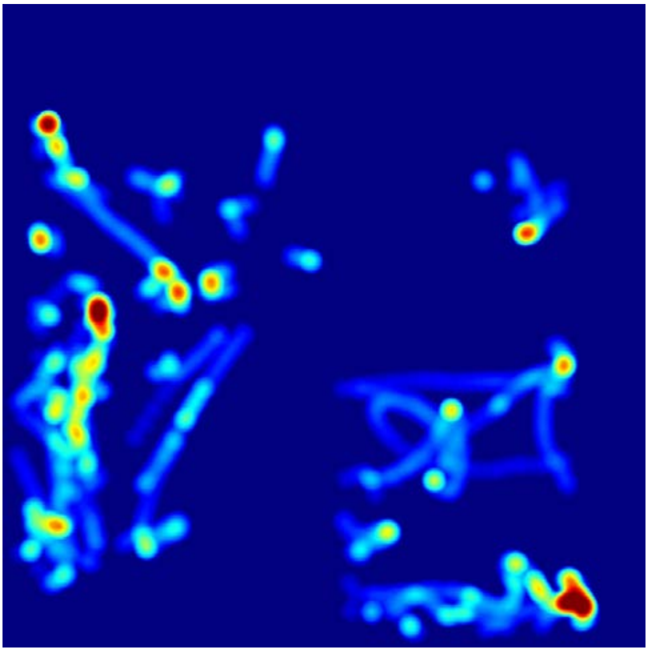


Fig. 5 - Converted data from a black and white gaze data map into a MatLab "Jet" color scheme Source - author

In the case of Aurela Sight, the first approach to depicting data consisted of creating a heatmap like depiction with appropriately blue, green yellow and finally red colors showcasing the different intensities of gaze attraction. Visually appealing and similar to the MatLab "Jet" colormap, the information was easy to understand and to pronounce quick assumptions [8], however it turned out to be difficult to use in further analysis, unlike that of the ground truth map style.

DATA ASSESSMENT

Once a formidable database is achieved, the textures undergo two stages of analysis. The first is human centered and relies on finding patterns and similarities between different test subjects and their gaze output. At this point the process of converting the black and white maps into an easier to understand heat map is crucial to understanding the strength and dispersion of different gaze attention spans on the architectural models.

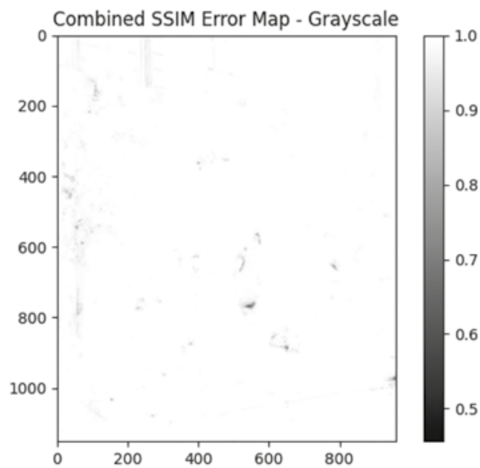
The second stage is quantitative assessment and relies on using python scripts that compare each of the acquired images against each other. By creating both combined maps as well as numerical results, the MSE and SSIM image comparison methods proved to be very useful in generating more indepth and detailed information that would normally be invisible and hard to calculate.

The Mean Squared Error (MSE) and Structural Similarity Index (SSIM) are image comparison methods that can be used to analyze the gathered results from the Render-to-Target (R2T) textures in the context of "Aurela Sight." The primary purpose of using these methods is to evaluate the accuracy and precision of the gaze data collected by the system, comparing the obtained gaze textures with each other.

When using MSE to analyze the gathered results from R2T textures, the squared difference between the pixel values of the collected gaze textures is calculated for each pixel [10]. The average of these squared differences across all pixels in the textures is then computed to obtain the MSE value. A lower MSE value indicates a higher similarity between the collected gaze textures, thus providing insight into the similarity at a per pixel level.

On the other hand, the SSIM method evaluates the similarity between two images by considering structural information, luminance, and contrast. In the context of gaze data analysis, SSIM can be used to compare the collected black and white gaze textures, just like in the MSE method. To apply SSIM for gaze data analysis, the structural, luminance, and contrast components of SSIM are computed for the collected gaze textures. These components take into account the correlation between pixel values, mean pixel values, and contrast between textures, respectively. After calculating these components, a weighted formula is used to combine them, resulting in the SSIM index, which ranges from -1 to 1. A higher SSIM index signifies a greater similarity between the collected gaze textures, suggesting better accuracy and precision in the gaze data collection process. This also provides additional feedback regarding numerical representation of all of the users ability to see certain architectural details and patterns, or not.

Fig. 6 - An example of a SSIM Error Map in grayscale visual representation. Source - author



A lower MSE and higher SSIM value will indicate that participants behaved in a similar fashion and that their gaze data is subconsciously replicable between each other. This would indicate that random gaze patterns would not form decisive results, as both these algorithms produce Error Maps [12] as a form of combining the given data set into one median texture. While technically sufficient for such early stages of development of the tool, the ability to provide more accurate and unbiased results give Aurela Sight a prospect for further development.

SUMMARY

While being at such an early stage, the program features many possible use cases, ranging from furniture design, to interior design, general architectural design, and more. Real time gaze and attention tracking results and their analysis through comparative methods of Mean Squared Error and Structural Similarity Index can provide unique feedback on how architectural designs are seen and embraced by digital world users [5], with a slight chance of providing insight on similarities of spatial perception in the tangible world. In the perfect scenario, a design would be tested in the early stages of conceptualisation through the means of Aurela Sight, possibly revised, produced and then again tested alongside real world eye tracking systems [7]. Gaze data provides useful feedback that if recorded correctly, can help influence change in the design process and possibly reduce costs for both the production and sale aspects of retail furniture. Future development is underway, and may yet show the research community how open source software development can help build a deeper understanding of architectural and interior design.

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