APPLICATION OF IMMERSIVE TECHNOLOGIES IN THE EARLY DESIGN STAGE IN ARCHITECTURE EDUCATION - A SYSTEMATIC REVIEW

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Abstract

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Keywords

Virtual Reality; Architectural Education; Gravity Sketch; Unity; Virtual Environments.

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ABSTRACT

This paper reviews existing research on the use of immersive technologies, Virtual Reality in particular, in various stages of the architectural design process. Nine research papers were systematically reviewed and analyzed. They were filtered down by using the *keywords:* 'Virtual/Augmented Reality, Architectural Education, Gravity Sketch, Unity and Virtual Environments' from two main databases that focus on digital and computer-aided design research: Cumulative Index about publications in Computer Aided Architectural Design (CuminCAD) and Elsevier's abstract and citation database (Scopus). The selection of papers was filtered down based on relevant approaches which investigate architectural design, creative thinking and teaching methodology using immersive technologies. Another criterion applied to the filtering process of the research papers is the exploration and integration process of new tools and overlapping external software to aid the existing workflow of the user. Our findings explore the evolution of immersive tools to highlight the advantages and disadvantages of virtual reality-based software and hardware, as a creative development tool in the field of education and practice. This paper also proposes a novel teaching methodology that incorporates immersive technologies in the early design phase of architectural education.

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ملخص

تستعرض هذه الورقة الوضع القائم فى الأبحاث التى تتناول استخدام التقنيات الغامرة، والواقع الافتراضي على وجه الخصوص، في مراحل مختلفة من عملية التصميم المعماري. تمت مراجعة وتحليل تسع أوراق بحثية بشكل منهجي، وتمت تصفية الأوراق باستخدام الكلمات المفتاحية التالية: "الواقع الافتراضي/ المعزز، والتعليم المعمارى، برنامج جرافيتي سكتش، برنامج يونيتي، والبيئات الافتراضية"، وذلك من خلال قاعدتي بيانات رئيسيتين تركزان على أبحاث التصميم الرقمي بمساعدة الكمبيوتر: الفهرس التراكمي حول المنشورات في التصميم المعماري بمساعدة الكمبيوتر (كيومنكاد) وقاعدة بيانات سكوبس للملخصات والاستشهادات التابعة لـ"السيفير". وتمت تصفية عملية اختيار الأوراق البحثية بناءً على الأساليب ذات الصلة التي تبحث في التصميم المعماري والتفكير الإبداعي ومنهجية التدريس باستخدام التكنولوجيا الغامرة. وكان المعيار الآخر المطبق على عملية تصفية الأوراق البحثية هو عملية الاستكشاف والتكامل للأدوات الجديدة والبرمجيات الخارجية المتداخلة لمساعدة سير العمل الحالي للمستخدم. وتدور نتائج البحث على استكشاف تطور الأدوات الغامرة لتسليط الضوء على مزايا وعيوب البرامج والأجهزة القائمة على الواقع الافتراضي كأداة تطوير إبداعية في مجال التعليم والممارسة. وتقترح هذه الورقة البحثية أيضًا منهجية تدريس جديدة تتضمن تقنيات غامرة في مرحلة التصميم المبكرة للتعليم المعماري.

الكلمات المفتاحية: الواقع الافتراضي، التعليم المعمارى، برنامج جرافيتي سكتش، برنامج يونيتى، البيئات الافتراضية.

1. INTRODUCTION: VR/VE EVOLUTION & ACCESSIBILITY

Since the introduction of immersive tools in the '90s, the architectural platform has utilised VR/VE (Virtual Reality/Virtual Environment) tools to evolve traditional design techniques and approaches (Alvarado & Maver, 1999). The use of immersive tools in various stages of architectural design allows the user to grasp space on a 1:1 scale via a virtual reality walk-through for design analysis and visualization. VR/VE utilisation has since evolved, by testing out various interactive techniques like 3D sketching and collaborative design methods in the VR/VE environment. In a similar timeframe, Bricken & Byrne (1992) explored VR as a new input tool to use as part of the design process in a summer workshop series. Achten et al. (2000) also explored the potential of VR software by developing a testing DDDoolz, a 3D voxel-based platform that allows the users to sketch in a 3D space. Given the direct nature of interaction offered in VR that is usually missed from using a traditional monitor, users are actively able to inhabit and interact with a digital space with the ability to directly modify and interact with the space via the built-in tool's set-up by the designer (Achten et al., 2000; Bricken & Byrne, 1992).

VR/VE technology integration has since been expanded upon by exploring different design approaches via updated modern software and hardware. Immersive hardware has also extended compatibility to industry-standard software to allow the user to export, edit and analyse their designs and function through multiple stages of the design process in VR. The design methodologies that incorporate immersive tools typically follow a preset system and workflow that is made accessible to the user.

The use of VR and VE tools for the first time can result in a steep learning curve (Schroeder, 1995). This is similar to using any new software or hardware and adapting to a new system and user interface. It is also important to acknowledge that advancing technology increases in accessibility and is less 'complex' with each iteration as it becomes more commercially available to consumers each year, this is due to the software UI (User Interface) and hardware designs evolving to appeal to wider consumer demographics instead of being limited to advanced academic and research platforms. This evolution of hardware and software design flattens the learning curve gradually with every iteration of VR/VE technology that is released to the public (Bricken & Byrne, 1992; Myers et al., 1999). Recent technologies remove various limitations of hardware setup, devices like the Oculus Rift device that was released in 2016 require several connections and sensors to set up, this can be compared to more recent hardware like the Oculus/Meta Quest which offers inside-out tracking and a single cable for charging and optional PC connection (Figure 1.). The simplification of the setup process by eliminating external sensors, additional cables, and a high-end graphic PC allowed for a quicker experience and an increase in accessibility to a wider consumer and professional demographic.
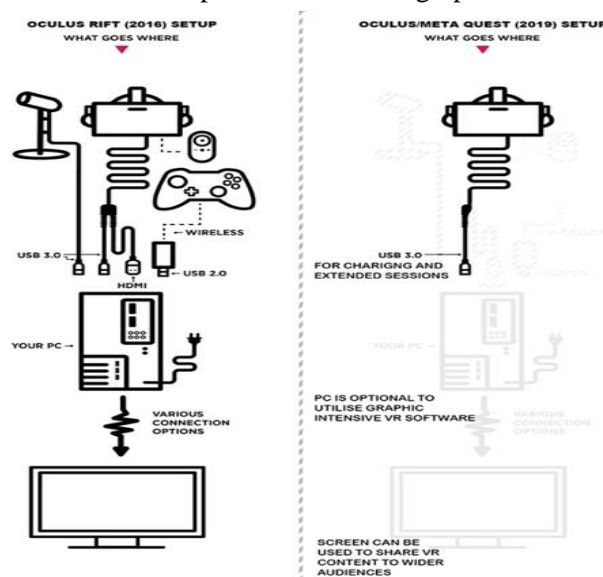

Fig.1: Hardware setup for Oculus Rift 1 and Oculus/Meta Quest 1/2

In architectural education environments, the use and integration of AR/VR technologies in the design process is still rare and if present at all, it is usually limited to a few weeks per semester to introduce, teach and implement immersive technology to students, this is due to the technology's complex setup which resulted in little to no practical implementation of immersive VR/VE tools in current design education. Simplifying the approach taken to set up and utilise this technology as part of the architectural design workflow becomes a crucial point when adopting the tool for practical design and academic implementation.

2. REVIEW QUESTIONS AND AIMS

Although various methods have been applied in past research to explore immersive technology, only a few scholars have justified the choice of software, or have deeply provided in-depth analysis to compare different VR platforms and potential conventional approaches to developing a design methodology that can be accessible and become an applicable addition to the architectural design process. In continuation to our previous research (Agkathidis, 2016), the current paper investigates which existing VR software and hardware is accessible and suitable to aid the architectural design process. In particular, this paper addresses the following research questions:

- How can we develop an educational framework incorporating virtual environments into the early stages of the design process in architectural education?
- What existing software and hardware can be utilised to achieve, develop and test this framework practically?

3. REVIEW METHODOLOGY

Our systematic review method consists of four phases (Figure 2.). 1) Article search through databases including Scopus and CuminCAD, 2) Screening of selected papers, 3) comparatively analysing and categorising each paper and its design methodology approach, 4) evaluating each software and methodology through charts and tables.
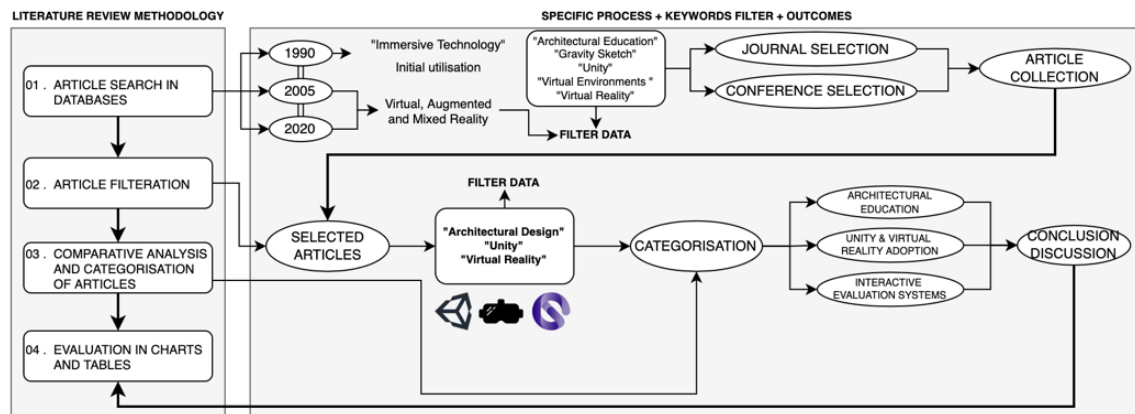

Fig.2: Literature Review Methodology

In the first phase of our research, two main databases that focus on digital and computer-aided design research were used: Cumulative Index about publications in Computer Aided Architectural Design (CuminCAD) and Elsevier's abstract and citation database (Scopus). These databases were selected due to their reliability and accuracy. The keywords searched include Virtual Reality; Architectural Education; Gravity Sketch; Unity and Virtual Environments in titles, abstracts and given keywords of the articles. The search results reveal higher numbers in conference papers than journal papers since digital design and VR/VE in architectural education continue to emerge in recent years as technology evolves. CuminCAD revealed the highest conference publication count for our search. CuminCAD is one of the main databases for digital design in architecture supported by ACADIA, CAADRIA, eCAADe, SIGraDi, ASCAAD and CAADfutures. In contrast, Scopus comprises mainly journal articles and book sections related to

our research. As a result of our filtered search, 57 academic publications were found. In the second phase, these articles were filtered by removing review publications and low-relevance articles. Furthermore, articles not dealing with VR/VE/AR or Unity in architectural education were removed, resulting in the remaining nine articles reviewed here. In the third phase of the literature review, the nine articles were categorised systematically and analysed according to the following: 1) architectural teaching methodology, 2) Unity & virtual reality adoption, and 3) integration of interactive evaluation systems. Finally, in Phase four, these categorised articles are analysed and compared to answer our research questions.

4. PAST & CURRENT RESEARCH ON VR/VE INTEGRATION IN ARCHITECTURAL DESIGN/EDUCATION

4.1. VR/VE in the 1900s

Some architects and researchers in the '90s have applied Virtual Environment (VE) tools to traditional architectural design methods. One of the initial highlighted research projects explore the use of a panoramic screen that displays a wide field of view, the display was located in a physical room that hosted up to 14 students per session, in addition to allowing the main user to present a series of pre-built projects to the students via the medium (Alvarado & Maver, 1999). This cinematic room setup is referred to as the Virtual Environments Laboratory (VEL). The design and development aspect of the paper is further explored through the integration of online learning and virtual live communication via a private network between two academic institutions which include: Strathclyde Institute and Mackintosh School of Architecture. VE exploration is also utilised by the students to assess their digital models, unfortunately, the files were limited in graphic capability and did not show as many details due to the low polygon count that had to be maintained to reduce the lag. This was a common obstacle involving the technological limitations that were available at the time. The paper successfully portrays the approach of digital tool integration available at the time and how the same approach can be used today with new immersive technology, to explore not only VR head-mounted devices but also the different VE approaches to involving multiple people in a single immersive experience.

In 1991, the VE Technology offered 10 students between the age of 10-15 to utilise the technology each week spanning throughout the Technology Academy summer program. A pre-session was prepared to allow the students to familiarize themselves with the platform through initially understanding the concept of how the technology works and later experiencing a series of demo virtual spaces. In a later stage, students worked in groups of three to share one computer with the VE setup. With the guidance of an instructor, students had the opportunity to explore the development of virtual spaces. Given the 'clustered' work environments, students had the ability to exchange knowledge and design approaches which resulted in various virtual worlds that were accessible in VE. The pragmatic approach of this series of workshops led to a practical understanding of the contributions that VR offered at the time, and hence an understanding of the possible implementations that VR can be adapted for in future iterations of the technology.

4.2. Interactive, Inclusive and Accessible Design: Voxel Design

Virtual reality was initially limited in graphical power and visualisation in the early 2000s. Voxel design was an innovative approach to accommodate this limitation, by utilising a building-block scheme to provide the user with the ability to create sculptural and structural forms in a 3D blank space in VR by stacking and colouring a number of cubes. DDDoolz has been developed by Bauhaus Universität in Weimar with a primary incentive to achieve a simple user interface that supports easy creation in a VR environment (Figure 3.). The interface also supported easy navigation and manipulation in the VR environment to support spatial understanding of the design at 1:1 scale (Achten et al., 2000).
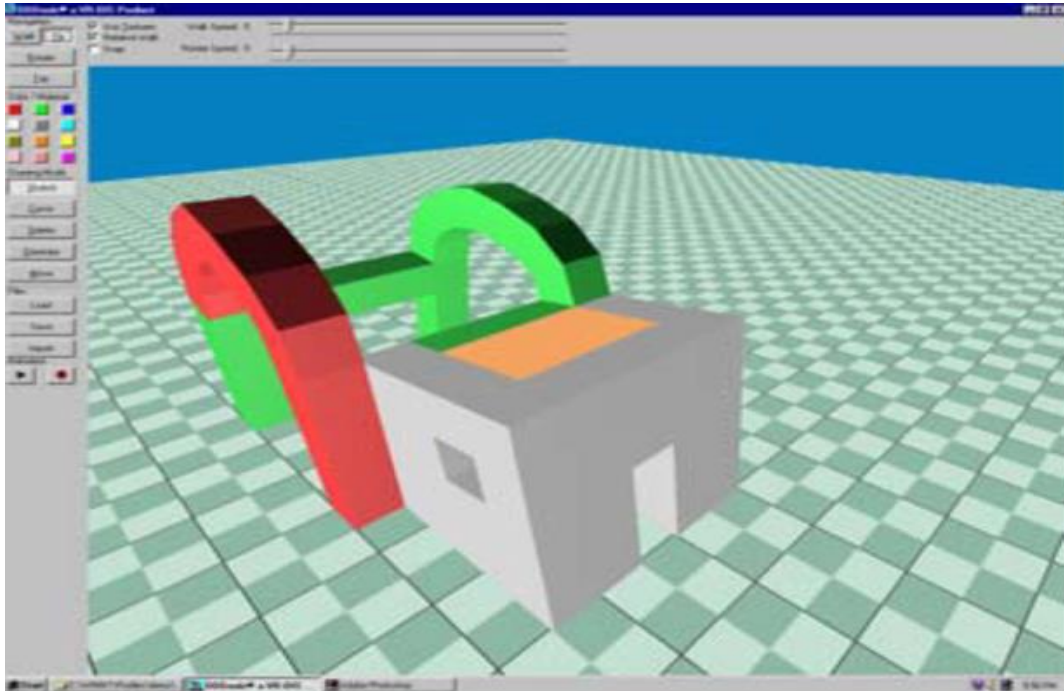
Fig.3: Sketch in DDDoolz (Achten et al., 2000)

Conventional architectural approaches involved site analysis; 2D sketches and 3D programme massing using physical models to develop the building design. The use of DDDoolz layered these stages in a more immersive layout, allowing the user to develop and experience quick sketch models for further analysis. Voxel Design becomes very effective in the initial design process as the user is forced to simplify their thought process into simple forms and shapes that can highlight the different proposed building programmes from 2D to 3D.

Voxel design is also adopted in a recent case study that utilises the popular multiplayer sandbox game, Minecraft, which was developed by Mojang (Delaney, 2022). The conducted research took place during the Covid-19 pandemic period, exploring remote collaboration, public participation/contribution and live feedback and connectivity to an ongoing public-site project. Minecraft is a voxel-based open-world sandbox video game that supported local and online multiplayer gameplay. The game offered a 'Survival 'mode which incorporates an open-world adventure, involving enemies, crafting tools and weapons to mine resources for building advanced items and shelter. The 'Creative 'mode which Delaney compares to LEGO building blocks, placed players in an infinite 3D blank 'canvas', allowing them to build and compose structures using the large array of material selections in the game.

The research tested the creative potential of voxel design that extends from Achten's research. The project utilised the Creative mode of the game to conduct a research study that focused on public participatory design open to a wide age range and various backgrounds. Given the popularity of the game, the project attracted various age groups, the younger demographic in particular that ranged between 16-24, the game's popularity was also complimented by how accessible it is mainly due to the various platforms the game has been ported into, including PC/Mac, gaming consoles and mobile devices. This is made possible mainly due to the low graphic requirements of the game. Public participation was conducted in a live site that was recreated in the virtual voxel environment. Each participant was given a plot in the open world with a copy of the same site to design and build on by following a particular design brief (Figure 4.).

Fig.4: Research output preview of the selected site, plot organization and site design outcomes (Delaney, 2022)

The voxel medium initially portrayed visual limitations but encouraged players/designers to think outside the 'box 'and creatively attempt to develop their designs using the in-game tools. The live design and multi-user implementation of this project also allowed for live feedback and a number of multi-user collaborations. The assessment of this project was conducted in a survey format after participants completed their designs. The survey outcomes revealed a positive outcome that showcased interest to participate in similar future projects mainly due to the simplicity of design and accessibility of the game. This research further emphasizes the importance of accessibility and simple user interfaces, this is also complemented by Mojang's recent announcement to allow users to explore and build their existing and future Minecraft projects in VR (Mojang, 2022). This offers the potential to further utilise VR as a design tool by expanding their virtual environments in the existing software to achieve a more immersive design experience.

4.3. Freeform Sketching & Accessible VR Software.

Barczik (2018) developed a study to explore interactive design and performative movement. Unlike the previous papers that have embraced voxel design, Google Tilt Brush is utilised in this research (Barczik, 2018). The software design of the application took an artistic approach, by allowing the user to sketch and layer a series of flat 3D brush strokes with various shapes and paint textures to create their compositions. In contrast to voxel modelling utilised in DDDoolz and Minecraft, Google Tilt Brush offered more expressive output, breaking free from the 'box 'and allowing designers to express detailed free forms. The study takes a *unique* theoretical and practical approach to the architectural design process by involving performative gestures that are recorded using the VR controller. "*Exploring movement in 3D and 4D space for architectural design has little if at all investigated*" - Barczik (2018). As a theoretical-based paper, it is interesting to see that the project and course structure applied by Barczik is not fixed, this is done by providing a flexible design methodology that allowed the student to adapt and utilise the VR tools without any limitations. One student embraced the performative aspect of the design brief

by focusing on "*non-immersive trace*", this excluded the immersive element of VR and only used the controller to blindly trace the body movement in physical space (Figure 5.).
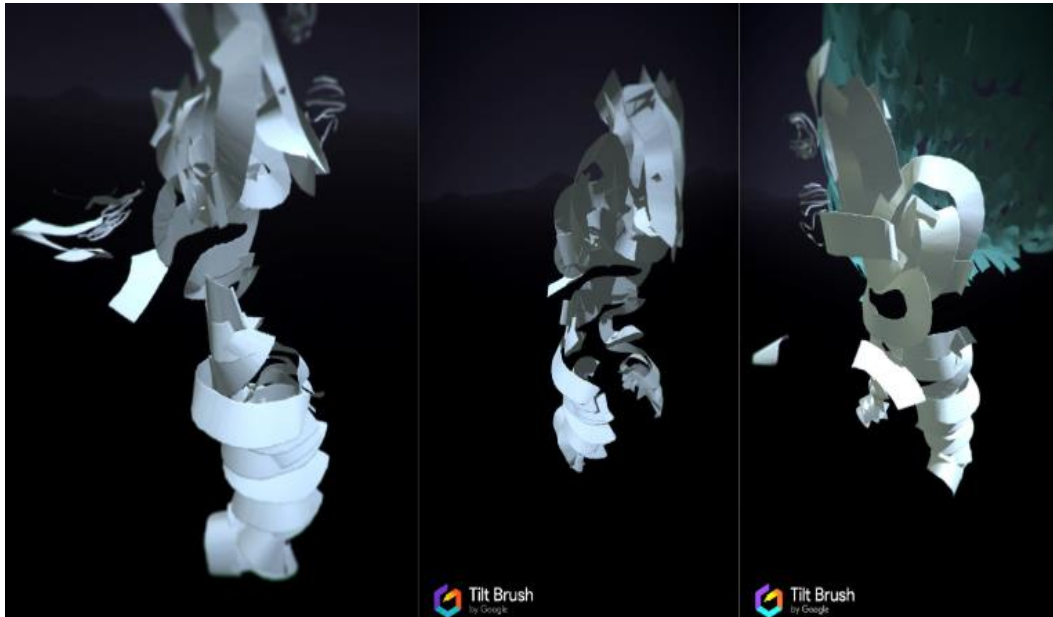

Fig.5: Non-Immersive Trace: Tilt brush Screenshot (Barczik, 2018)

As a theoretical-based paper, exploring this form-finding technique resulted in the ability to trace, analyse and extract movement into external software for further modification and refinement. Given the artistic intent of Google Tilt Brush, the model mainly consisted of flat brush strokes layered to create a form that has no volume. The output of these models required further refinement using external software like Rhinoceros – a 3D CAD tool. The external tool is used to extrude the multiple flat surfaces into 3D. This showcased a limitation within the software as it prioritised the visual aspect of the 3D sculpture, with little control to edit and modify the 3D sketch in VR.

4.4. Advanced Software & Interactive Design Limitations

Software like Google Tilt Brush used by Barczik (2018) falls under the digital sculpting category, enabling the user to sketch in 3D space. Other software like Google Blocks and Gravity Sketch follow similar frameworks to Google Tilt Brush, with different user demographics in mind for each platform. This is made clear when highlighting the toolset and export options that each software offers. Asanowiz's research explores a similar approach to Delaney's (2022) and Barczik's (2018) paper. The research was executed by enabling live model interaction within the process of creation while considering the possibility of implementing the idea of "direct design" (Asanowicz, 2018).

The main limitation of the software is primarily the lack of design tools that enable the user to scale and modify specific faces of the model to achieve higher details in their 3D sketches. Complex tool limitations can be overlooked when software like Google Blocks and Google Tilt Brush aims to achieve higher accessibility and quick sketch development, in contrast to precisely detailed models and sculptures. The author discusses the student's response to the software while highlighting the ease of accessibility due to the efficiently designed user interface that supports a "fast learning curve" (Asanowicz, 2018).

By introducing an accessible modelling tool to a cohort of students that might have not experienced VR before, accessibility becomes an important key factor that will allow students to embrace the medium in the future and potentially explore more advanced tools like Oculus Medium, Oculus 'powerful VR sculpting app. The student's work is further assessed with a comparative study between the physical architectural models and the digital models developed in VR. The paper concludes with potentially exploring a future Game Design course that enables the users to import their 3D polygon models to explore

interactivity via game-engine software including Unity or Unreal Engine to elevate the "Static visuals" and explore potential interactive concepts within their developing building designs.

4.5. Game Engines, Interactive Design & Immersive Assessment

Game engine software has evolved with the intention to appeal to various platforms including architectural and visualisation professions. Game engines like Unity follow a similar UI design language to 3D design software Autodesk 3DS max (Figure 6.). This UI similarity allows users to increase the adoption of the platform due to its familiar UI design. Game engines provided an extra layer to the design development approach, giving the designer the ability to experiment with interactive applications to their existing designs.
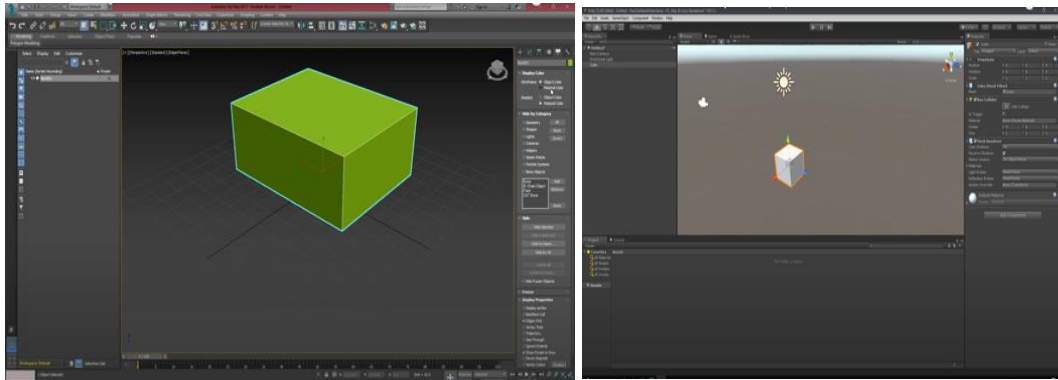

Fig.6: Software interface comparison Autodesk 3DS Max (Left) and Unity game-engine (Right)

The VR scope box focuses on enabling the user to visualize details in 3-dimensional space at a 1:1 scale with accurate material representations (Morse & Soulos, 2019). The research embraces the Unity game engine to explore CAD-developed models in sectional detail, allowing the user to visualise any part of the imported building segment in sectional view to preview internal material layers and details. The idea of evolving the static architectural 3D model into an interactive experience in a VR system elevates the immersive experience for analysis and development. The approach to incorporating a game engine into the design process can result in a steep learning curve. The learning curve can be bypassed by developing a preset setup that integrates these assessment tools to efficiently be taught to participants to import their own designs. Morse and Soulos (2019) took this approach to export the Unity assessment tool setup into a preset file that was made accessible to the students and teachers to import the designed models for reviewing and assessment in several ongoing design projects.

Assessment of design through the utilisation of immersive technologies can lead to more informative analysis, VE tools provide the ability to inhabit a design in VR, or to place the digital model in physical space using AR. Weissenböck (2021) utilises AR in her research to explore remote learning approaches to architectural education. The course was hosted remotely, students were introduced to Rhinoceros3D and Grasshopper and were assigned to work in groups to develop their designs. Each participant was then asked to individually place the group design in their own physical space and adapt the form using physical QR-code/ArUco Markers. These markers were placed on the wall or floor to track the position of the model in the physical space using AR and Grasshopper. The series of markers provided a physical interactive element that allowed the user to make any adjustments to the model by moving the ArUco Markers to adjust the design to suit their physical space (Figure 7.).

Fig.7: Project 1.1: "flow follows fologram"; design ideas (top), the process of scanningArUco markers on the wall with the smartphone app, and adapting parameters with sliders in the ARapp, which are synchronized to the computer (Grasshopper window and Rhinoceros model window) (middle and bottom).98|eCAADe 39- CAAD and education - Volume 2

5. ANALYSIS AND DISCUSSION OF THE FILTERED PAPERS

Bricken and Byrne (1992) researched one of the first initial uses of immersive technology in architectural development according to our analysis. The VR-based project took place during a summer workshop series, involving multiple users to develop and create a series of virtual spaces using Swivel, a 3D modelling software, and later experiencing them on the VR platform. The immersive outcome of this project resulted in positive and "*enthusiastic feedback*", based on the follow-up survey results from the participants (Bricken & Byrne, 1992).

In a similar time frame, Alvarado & Maver (1999) researched the VEL (Virtual Environments Laboratory). The VEL was categorised as a VE system that consisted of a cinematic panoramic display. Given the limitations of the technology in the 90s, the visualisation of the designs was limited due to graphical power. Given this minor setback, users were still able to utilise the medium and experience their designs from a new perspective. The VEL also supported up to 12 users at once, with the addition of remote connectivity with different institutions to promote collaborative learning and development.

Achten et al. (2000) followed up in the early 2000s, delving into the interactive aspect of digital design. Achten et al. worked on DDDoolz, which explored the concept of Voxel sketching in VR. Developing compositions with cubes was limiting, but the simplified medium provided more room for creative composition and immersive exploration that was accessible to the user. Voxel design was seen as accessible mainly due to its simple visual, this was proved in a more recent project by Delaney (2022) using Minecraft. The modern video game/software welcomed a large number of contributors due to the platform's popularity. The project also resulted in a positive outcome when it came to addressing inclusive collaborative and interactive design.

The integration of interactive design becomes a focal point when it came to utilising game engines as part of the design process. Game engines like MediaStage and Unity were utilised as a part of a study to explore interactive and immersive-based assessment (Morse & Soulos, 2019; O'Coill & Doughty, 2004). Game-engine-based software enabled the students to develop immersive experiences that involve interactive input systems that can be used for spatial analysis and visualisation, incorporating this process played a major role in the teaching methodology approach as it gave control to the student to customise their interactive and immersive experience. The use of parametric design complements further the integration of interactive design. Rhinoceros3D/Grasshopper enables this experience through various plugins that enable different VE immersive tools to be used. In a recent study, AR was paired with multi-marker tracking to enable the user to translate and modify their 3D parametric models to fit in specific locations

through the AR lens (Weissenböck, 2021). The project took place virtually, enabling the students to work remotely and collaboratively in groups throughout multiple iterative design stages to develop a single model that adapted to each individual user's physical space.

Free-form and design testing are also addressed as an extension of Achten et.al (2000) research. Removing the restrictions of voxel design and enabling detailed 3D models. Google Tilt Brush and Google Blocks are both utilised in different design projects in the academic platform. The mediums were used to explore form-finding and design exploration techniques in VR. The use of VR tools led to a series of digital models developed by the students. These models were assessed and contrasted with the physical models developed in the earlier stages of the design project. Asanowicz (2018) assessed the difference between the two approaches and takes a practical approach to test out the level of interactivity that is enabled by the user to assess the quality and design outcome. Barczik (2018) Took a similar approach but instead focused more on the performative aspect that theorised the variation of form-finding techniques in VR throughout the initial architectural design stages.

6. VR/VE TOOLS & POTENTIAL DESIGN TECHNIQUES

VR/VE tools can lead to unique results that can vary based on the adopted software and design brief. This paper aims to utilise software that is accessible and offers a set of advanced tools that can lead to more complex results. Consequently, the software must also offer multiple export options and enable multi-user support for potential collaborative design. Based on the analysed papers, most of the software used showcased some limitations including, design toolset, accessibility and ability to export the model for further development (Table 1.).

Table 1: Softwares list used for VE architectural development

Software	Release Date	XR type	Hardware Support	Techniques used	Import / Export options	Advanced tools?	Multi-user support	Integration in design studio	Reference
Swivel	1992	VE	PC/VR	3D modelling	NO	NO	NO	NO	(Bricken & Byrne, 1992)
VEL	1999	PC	PC	Visualisation	NO	NO	YES	YES	(Alvarado & Maver, 1999)
DDDoolz	2000	VR	HMD	3D Voxel Sketching	NO	NO	YES	YES	(Achten et al., 2000)
MediaStage	2004	VE/ VR	PC	3D Visualisation	NO	NO	NO	YES	(O'Coill & Doughty, 2004)
Unity	2005	VE/VR/AR	PC/Mobil/ PCVR	Site Analysis	YES	YES	YES	YES	(Morse & Soulos, 2019)
Minecraft	2011	VE	PC/Mobil/ PCVR	3D Voxel Design	NO	NO	YES	NO	(Delaney, 2022)
Rhinoceros/ Grasshopper	2014	VE/VR/AR	PC/Mobil/ PCVR	3D model extension	YES	YES	NO	YES	(Weissenböck, 2021)
Google Tilt Brush	2016	VR	Oculus Quest/ PCVR	3D Sketching	YES	NO	NO	YES	(Barczik, 2018)
Google Blocks	2017	VR	Oculus Quest/ PCVR	Polygon 3D sketching	YES	NO	NO	YES	(Asanowicz, 2018)
Gravity Sketch	2017	VR	Oculus Quest/ PCVR	3D Sketching	YES	YES	YES	NO	**No publications on this software**
VR Sketch	2018	VR	Oculus Quest/ PCR	SketchUp VR control/ modelling	YES	YES	YES	NO	**No publications on this software**

7. CONCLUSION

Throughout the filtered papers, only four papers have attempted to integrate VR and AR tools as a substantial part of the design methodology. Substantial use is defined by the level of VR/AR technology utilisation throughout different stages of the architectural design process, instead of limiting the tool for visualisation purposes only. Each of these papers utilised VR and AR using different techniques. Some enabled the student to Sketch, explore, alter and assess their designs throughout different stages of the project, others showcased the remote potential for collaborative design and assessment techniques between peers and the lecturer (Asanowicz, 2018; Barczik, 2018; Morse & Soulos, 2019; Weissenböck, 2021).

Furthermore, according to Table 1., we have identified three primary software that can be implemented into the developing design methodology. Softwares include 1) Gravity Sketch, 2) VR Sketch and 3) Unity. Little to no research has been done using Gravity sketch. Even though the software showcases great accessible potential to be used as sketching, modelling and refinement tool throughout the architectural process. Gravity Sketch is a recent tool released in 2017, housing a number of design tools like 3D sketching, edge-grab, massing, surface, scale, materiality and others. As an extension to this, Gravity Sketch also enables model import and export in various formats that enable external software compatibility. Site models can be imported to scale to allow for 1:1 scale sketching and design exploration. VR Sketch is the second software that users will import their designs into via SketchUp 3D. No research has been published using VR Sketch as a modeling collaborative tool. The software showcases great potential as a collaborative and immersive tool. As a plugin to Sketchup, the user has remote access and control to a SketchUp model in VR with the addition of the SketchUp modelling tools. The Unity game engine will finally combine the interactive element to allow the user to develop, import and assess their designs on the VR platform.

Finally, having analysed the different pedagogic approaches in the integration of VR/AR technologies into the design studio process, we propose a novel design and teaching framework enriching the generative design methodology proposed by Agkathidis (2016), by integrating VR/VE tools and exploring contextual based problem-solving techniques similar to the research done by (Delaney (2022). Throughout the design and interactive process, the design workflow can cycle through multiple iterative stages, allowing the users to refine their designs throughout the project (Figure 8.). The proposed framework is an output of the review that has been conducted. The framework will be tested and evaluated in design studio classes in our future work, aiming to provide a conventional methodology for immersive architectural design.
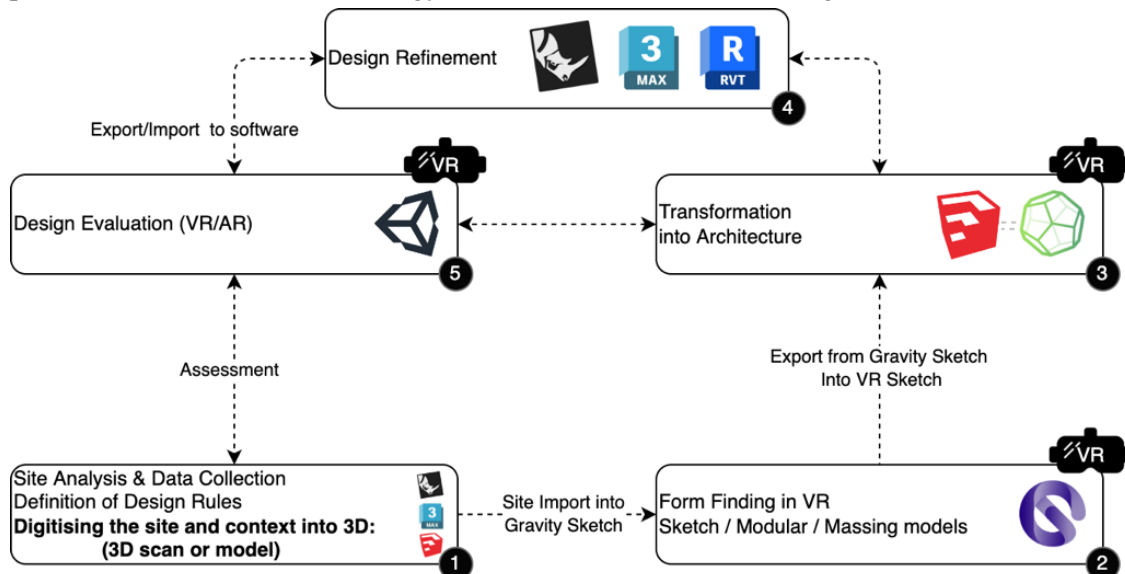

Fig.8: Design Methodology: Design Framework

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REFERENCES

- ACHTEN, H., VRIES, B. DE, & JESSURUN, J., 2000. DDDOOLZ *A Virtual Reality Sketch Tool for Early Design. 18-19 May 2000 Fifth Conference on Computer Aided Architectural Design Research*, Asia, Singapore,451–460.

- AGKATHIDIS, A. 2016. *Generative Design: Form-finding Techniques in Architecture (Form + Technique)*. Laurence King Publishing.

- ALVARADO, R. G., & MAVER, T., 1999. *Virtual Reality in Architectural Education: Defining Possibilities.* ACADIA Quarterly, 18 (4), 7-9

- ASANOWICZ, A. (2018). *Digital Architectural Composition in Virtual Space. 19-21 September 2018 Thirty Sixth Conference on Computer Aided Architectural Design Research*, Lodz, 451–460.

- BARCZIK, G. (2018). *From Body Movement to Sculpture to Space Employing Immersive Technologies to Design with the whole Body. 19-21 September 2018 Thirty Sixth Conference on Computer Aided Architectural Design Research*, Poland, Lodz, 781–788.

- BRICKEN, M., & BYRNE, C. C. M., 1992. *Summer Students in Virtual Reality: A Pilot Study on Educational Applications of Virtual Reality Technology*. 1992 Washington Technology Center, 199-217.

- DELANEY, J., 2022. *Minecraft and Playful Public Participation in Urban Design. Urban Planning*, *7*(2), 330–342.

- MOJANG., 2022. *Minecraft in Virtual Reality*. https://help.minecraft.net/hc/en-us/articles/360057619052-Minecraft-in-Virtual-Reality

- MORSE, C., & SOULOS, F., 2019. *Interactive Facade Detail Design Reviews with the VR Scope Box. 21-26 October 2019 ACADIA – Ubiquity and Autonomy*, Austin, Texas, 422-429.

- MYERS, B., HUDSON, S. E., & PAUSCH, R., 1999. *Past, Present and Future of User Interface Software Tools*. Pittsburgh, Pennsylvania: Carnegie Mellon University.

- O'COILL, C., & DOUGHTY, M., 2004, *Computer Game Technology as a Tool for Participatory Design*, England, Lincoln, 12-23.

- SCHROEDER, R., 1995. *Educational Applications, Learning from Virtual Reality Applications in Education. In Virtual Reality 1*. 33-39.

- WEISSENBÖCK, R., 2021. *Augmented Quarantine An experiment in online teaching using augmented reality for customized design interventions. Thirty Ninth Conference Proceedings on Computer Aided Architectural Design Research*, Novi Sad, Serbia, 95–104.