AUGMENTED MASONRY DESIGN

A design method using Augmented Reality (AR) for customized bricklaying design algorithms

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Abstract. The *Augmented Masonry Design* project presents experimental research about developing and applying Augmented Reality (AR) technology for customized design algorithms, exploring a real-time, interactive, and spatial-free design method for the early architectural design stage. We aim to resolve the current 2D-based design limitations and provide architects with a 3D-4D immersive perception in AR for a practical and easy-to-use design method. Furthermore, with reference to the Covid-19 pandemic, we propose that this method could break through site accessibility and constraints by breaking the barriers of physical space. Towards this aim, we apply the *Augmented Masonry Design* into two prototypes: a) user interface (UI) immersive design, in which interactive inputs will communicate with design algorithms in AR through the inputs from the screen-based UI on mobile devices (e.g., smartphones and tablets); b) intuitive interaction immersive design, in which interactive inputs will be translated to design algorithms directly in AR through hand gestures on head-mounted devices (HMD) (e.g., *Microsoft HoloLens*). Our Findings highlight the advantages of immersive design in the initial stage of architectural drafts, which gives designers better spatial understanding and design creativity, as well as the challenges arising from the limitations of current AR devices and the lack of real physical simulation in the design system.

Keywords: *Augmented Reality (AR), Immersive Design, Customized Algorithms, Masonry Design*

1. Introduction

In 1950, the rise of CAD transformed architectural design from hand-drawing design to the stage of computer-drawing design. Since then, architects gradually removed the shackles of pen, paper and board in the design method, and presented their creations through computer graphics (Lo et al., 2020). In the past twenty years, computers have evolved to provide a large number of different design tools covering the area of architectural design editing and analysis (Schneider and Petzold, 2009). Nevertheless, the traditional screen-based visualization method used for design and analysis lacks the actual scale of the architecture, and limits how well the architects understand the space through a computer, as drawings are done outside the building site without testing the design concept onsite, hence there might be differences between the design and final construction (Nguyen et al., 2014).

The last decade has witnessed the explosion of new technologies, and their impacts have dramatically changed architectural design methods (Huang et al., 2018). For instance, AR technology, with the characteristic of overlapping the holograms on the actual physical world and connecting interactions between human and digital data in real-time, is at the forefront of the immersive methods applied in the architecture and engineering field for spatial experiment, interaction, visualization, and immersing users in an augmented world to enhance collaboration between designers, digital outcomes, and physical space (Sampaio and Henriques, 2008). Greg Lynn is one of the first architects to use AR in the architectural design process. He places holographic versions of digital models in existing environments and manipulates them concerning the context for design outcomes visualization. Although the architectural modelling method has fundamentally changed in its history, the AR tools currently integrated with the corresponding design methods are mainly limited to only enhanced visualization. Very few projects attempt to solve the challenge of modelling in an immersive environment, which requires a new input method to eliminate the traditional mouse-keyboard combination (Coppens et al., 2018). Moreover, relying on 2D equipment for 3D operations is ineffective, because it does not provide the exact dimension of freedom and senses. So architects began to use new technology to explore immersive design methods and eliminate screen-based 2D restrictions in the early design stage (Song et al., 2021).

This paper proposes a novel design method, verified by design experiments, using AR for customized design algorithms by combining the unique characteristics and functions of AR to find out how AR immersive technology is changing and evolving the conventional design methods in architecture.

2. Research Methodology

The *Augmented Masonry Design* research project proposes an AR-assisted immersive design method consisting of two phases: a) UI immersive design, in which interactive inputs will communicate with design algorithms in AR through the inputs from the screen-based UI on mobile devices (e.g., smartphones and tablets); b) intuitive interaction immersive design, in which interactive inputs will be translated to design algorithms directly in AR through hand gestures or ArUco marker recognition on head-mounted devices (HMD) (e.g., *Microsoft HoloLens 1*). The task of this research is to use AR immersive technology to develop customized algorithms for the early architectural design stage of masonry structures. The reason for choosing brick structures is because bricks are the basic building unit for many architectural structures and meet the requirements of parametric design and AR interaction, which can conveniently and intuitively validate whether the proposed AR-assisted immersive design method is feasible.

The employed immersive design workflow (Figure 1) is driven by an instant connection between 3D-modelling software (*Rhinoceros 7*), parametric design environment (*Grasshopper*) and AR holographic immersion plugin (*Fologram*). *Fologram* is a third-party API developed by architects for architects, which could extract human gestures, screen taps, device location and mark information, and the *Fologram* App UI provides a bridge to interact and modify the related parameter sliders in parametric design from *Grasshopper* through AR. The *Fologram* plugin works with its integrated graphical algorithm editor *Grasshopper*, which are ubiquitous tools in architectural design, and can easily be integrated into established immersive design workflows.

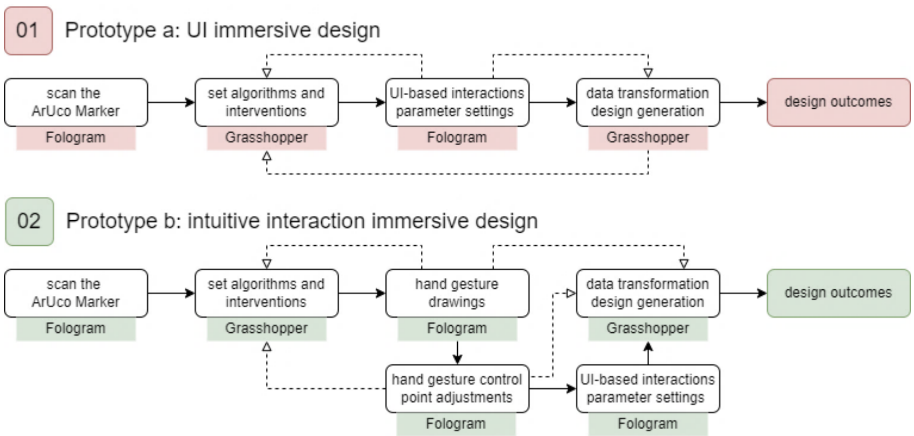

Figure 1. The flowchart of *Augmented Masonry Design* research. It describes each key step of the AR-assisted immersive design method using the UI immersive design prototype (in red)

and the intuitive immersive design prototype (in green). The related plugin and software are shown below in each step.

In the *Augmented Masonry Design* workflow, the hardware includes a handheld device – *iPhone 11*, and an HMD – *Microsoft HoloLens 1*. We also use a laptop for back-end running and debugging. These devices are connected to a WIFI router in the same IP address network environment for transforming the data from different stages, and live streaming comments on design software and plugins to visualize and output response ports. We will test our workflow by conducting two design experiments with the UI and gesture-based design input method respectively in order to apply the workflow on different AR devices and different levels of immersion. These two different experiments can verify the feasibility and limitations of immersive design multi-dimensionally.

3. Experiments and Findings

3.1. PROTOTYPE A: UI IMMERSIVE DESIGN

For the UI immersive design tool, we applied an AR UI that can extract the basic unit and parameter setting from the corresponding design algorithms in design software (*Rhinoceros 7 and Grasshopper*). This tool enables designers to achieve onsite real-time designs and visualization modifications through UI-based interactions from screens, such as parameter settings, data adjustments, and marker recognition in AR. The design algorithms have already been pre-set from our design library, representing different brick-based structures. Architects can also customize the design algorithms and interventions according to their needs and extract interactive parameters in our open platform AR UI through *Grasshopper*.

For example, we use the design of a brick column to validate the UI immersive design tool. First, the geometric concept of the design coordinate was based on an ArUco marker, that can be placed on-site on the floor as the centre point or the reference point of the brick column. After scanning the marker through the smart AR device (*iPhone 11* for this prototype experiment), the design coordinate will be picked up from physical to virtual in *Grasshopper*. Second, the adjustable values, as well as parametric definitions, will be incorporated in the *Grasshopper* according to users' design algorithms. These values include brick size, the number of bricks per layer, brick angle, proportions, column rotation of each layer, column pattern, as well as the height of the column, etc. Designers can add or modify parameters for their customized algorithms and interventions. Third, the designers can build their own AR brick columns with AR UI by developing and adjusting the related parameters through device screen inputs and modifying the structure outcomes onsite as holograms (Figure 2). Last, the outcomes will be recorded in *Grasshopper*. Multi-designer or remote users can scan the same ArUco maker to access the design outcomes, as well as share and modify the design in an instant design environment, providing a remote design strategy.

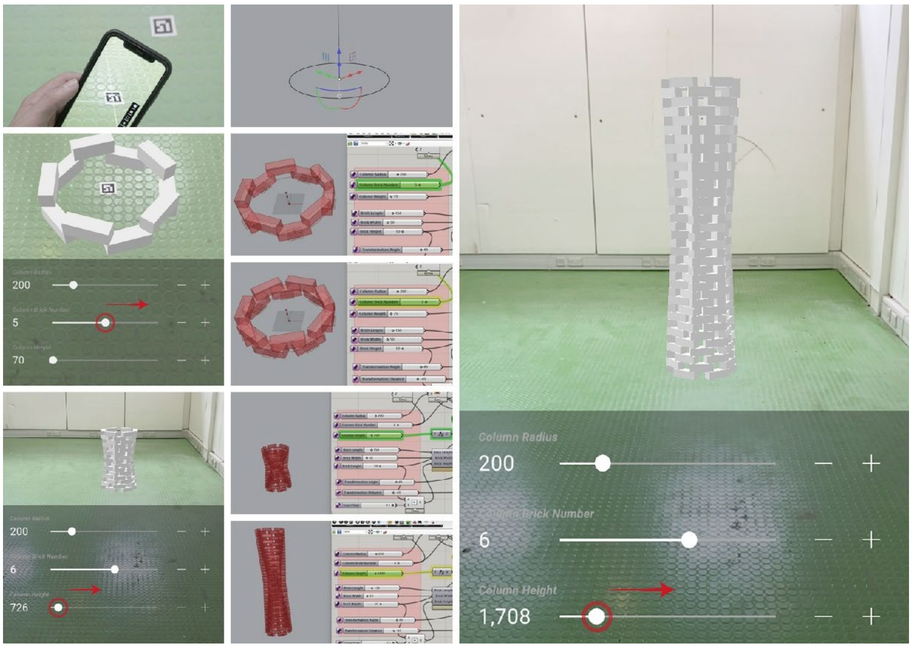

Figure 2. The process screenshots of UI immersive design for designing a brick column from the *Fologram* App on *iPhone 11*. The designer can scan the ArUco marker to define the design coordinate. After setting the design algorithms, the designers can interact with the parameter sliders from AR UI, such as brick size, number of bricks per layer, column radius, column height, etc., and preview the outcome in real-time onsite as holograms in AR.

In summary, the UI immersive design tool does fulfil our pre-determined assumptions. We successfully designed various columns with different algorithms in our UI. Through the parameter adjustment of the screen UI and the real-time onsite preview of the holographic model, the designer can better experience the sense of space and scale. Our tool provides an appropriate and intuitive experience for design feedback and modification. Ubiquitous mobile devices such as smartphones and tablets can be used as AR UI tools, which will make UI immersive design easier to be popularized and accessible. However, the UI immersive design tool has some limitations as well. For example, the UI-based design method constrains the possibility of design algorithms by only adjusting the limited parameter sliders. For some complex or curved surface designs, the UI-based physical recognition method can not provide input methods other than the basic ArUco maker for the coordinate design points, which are generated with linear directions as columns. Moreover, interacting with a small screen naturally lacks a more integrated experience. Designers need to hold the smart devices by hand and experience sensory holograms through the screen, which is not an intuitive immersive experience. The screen-based holographic visualizations will cause tolerance in information transmission and spatial glance.

3.2. PROTOTYPE B: INTUITIVE INTERACTION IMMERSIVE DESIGN

For the intuitive immersive design tool, we employed methods of gesture recognition, path tracking, and ArUco markers tracking to transform intuitive human movements and hand gesture interactions into design algorithms. The basic parametric design logic has been pre-determined in our database. The key parameters such as spline curves and Nurb surfaces, which determine the shape of design outcomes, will be input intuitively through the designers' gesture tracking and recognition in the AR environment. Designers can develop and customize the parametric design logic and the critical interactive parameters according to algorithms through *Grasshopper*.

For example, we use the design of a brick wall to validate the intuitive immersive design tool. First, the geometric concept was based on an ArUco marker, that can be placed on-site on the floor as the centre or reference point of the brick wall. After scanning the marker through the HMD (*HoloLens 1* for this prototype experiment), the design coordinate will be picked up from physical to virtual in *Grasshopper*. Second, the designer can use the 'tap and hold' hand gesture in *HoloLens* to draw the virtual spline curve of the brick wall next to the centre point in AR. The spline curve will be displayed as holograms onsite with several control points on it for the user to modify and adjust the shape. Third, in parallel, the spline surface will be generated and extruded directly along the spline curve with AR holographic grid control points for the interactive adjustments. After the spline curve is determined, the brick holograms will fill the surface automatically. Designers can adjust the numbers of bricks, the angle of bricks, the brick structure density, etc., by using the same method in prototype a, or even set interference points for more customized algorithms. Last, the outcomes will be recorded in *Grasshopper*, which also supports multi-designer outcome sharing and remote collaborative design functions (Figure 3).

In summary, the intuitive immersive design tool indeed achieved different brick wall designs with corresponding algorithms. This approach gives users a deeper immersion in that the users' hands are liberated and the virtual model changes from a screen-based AR experience to a head-mounted one. Moreover, the variety of design outcomes is broadened due to gesture recognition and other more flexible parameter inputs and interactions through AR. However, the intuitive immersive design still has some limitations. For example, the *HoloLens 1* and similar HMD devices are still quite expensive and therefore not available to generic users. Due to the extensive calculation of interactive information transmitted in this prototype, there are delays between gestures and results in the entire real-time design process. Therefore, optimizing the parameters involved will improve the user experience and system fluency. Moreover, the gesture-based manually entered lines are full of freedom, which causes the outcome surface to be unsmooth or challenging to control. Therefore, optimization functions such as limitations for gesture inputs, rebuild smoothness, and Z-axis alignments should be added to optimize the spline curves for better final outcomes.

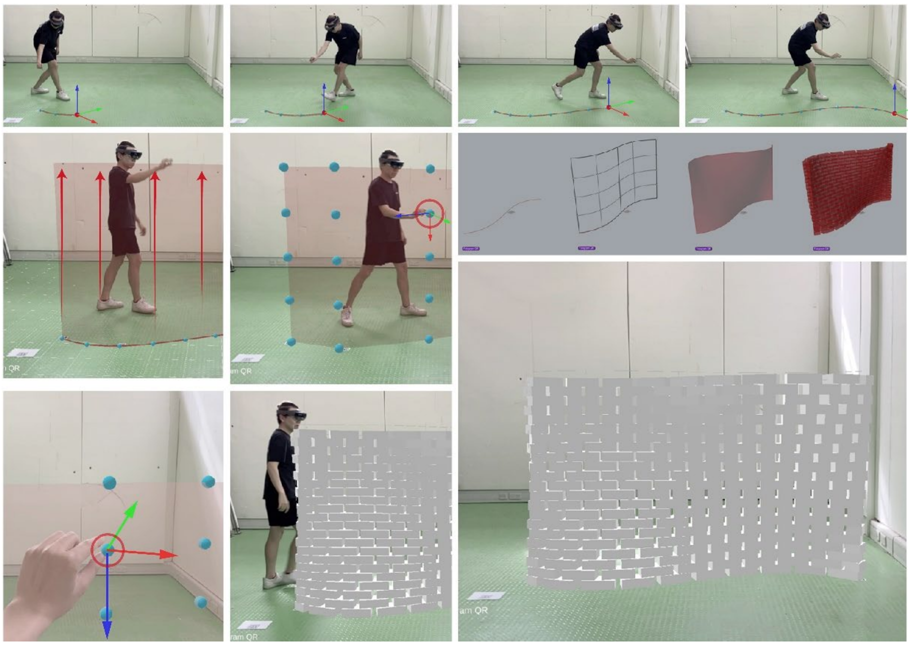

Figure 3. The process screenshots of intuitive interaction immersive design for designing a brick wall structure from *Fologram App* on *HoloLens 1*. The designer can scan the ArUco marker to define the design coordinate. After setting the design algorithms, the designer can use hand gestures to draw and point out the spline curve. After modifying the spline curve, the corresponding spline surface will be generated with grid control points. The designer can interact with the surface in AR. After the surface is determined, the bricks will be generated in real-time onsite as holograms.

4. Conclusion and Discussion

The *Augmented Masonry Design* research developed and verified an AR-assisted immersive design method that successfully applies the customized design algorithms in the AR environment, exploring a real-time, interactive, and spatial-free design method in the early architectural design stage for brick structures (Figure 4). Closely practising the AR-assisted design process as well as analyzing the outcomes, it can be concluded that the proposed immersive design method does fulfil our pre-determined assumptions and offers a new way to modify design drafts and preview onsite locations through AR in real time. The employment of AR technology provided the illusion of actual spatial objects. It aided real-time evaluation and instant modification of design proposals in the early stage. Additionally, architects are able to preview their digital designs out of the sketch or computer screen, as well as interact and communicate with the related onsite physical environment. This onsite design and preview functions break the conventional 2D-based design method, providing designers with a 3D-4D immersive perception in AR for more practical design. Moreover, the application of AR technology in the early architectural design stage enables the users to improve their cognition and understanding of space, triggers reflections and remodelling of the architectural design process, and cultivates their design creativity and outcome variety. Our AR-assisted design method gives architects more freedom, as well as its remote collaboration and multi-designer outcome-sharing functions break through the constraints of conventional 2D-based design media.

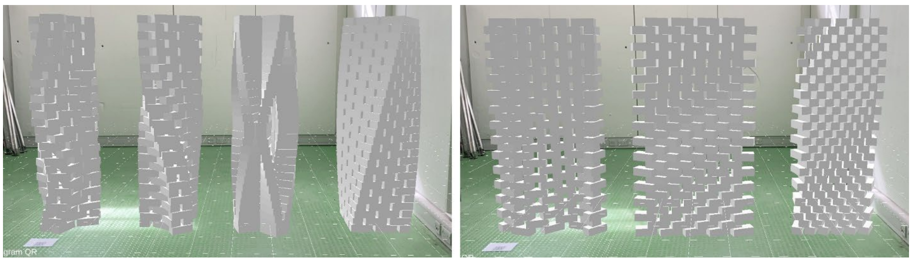

Figure 4. The screenshots of the *Augmented Masonry Design* research outcomes from the *Fologram App* on *iPhone 11*. Designers used different immersive design algorithms and interventions to create multi-variety brick-based structures, including brick columns (left) and brick walls (right).

However, there are limitations and space for further improvement. The current immersive design method is only suitable for simple parametric design, and there are apparent restrictions on the amount and functions of interactive parameter settings. The AR-assisted design process and related verifications are only carried out in initial discrete structures such as brick-based structures. Whether this workflow is suitable for other more complex architectural scale designs remains to be verified by future experiments. Moreover, the sensors of AR devices are affected by the surrounding light condition. If too much or too little UV light occurs in the natural environment, for instance, the holographic model sometimes has difficulties locking a model in a specific place. Consequently, the holograms always drift by the surrounding environment's interferences. Sometimes, it is necessary to restart the device and re-scan a QR code to correct the location. In further research, extra sensors, such as *Kinect*, are needed for helping to scan the onsite design environment and the design base precisely to reduce the unstable disadvantages of current AR. Additionally, this immersive design method lacks a physical simulation and a feedback system to make the design results easier to build for the future construction stage.

Finally, our *Augmented Masonry Design* project provides designers with direct design input and interaction methods besides pen and traditional mouse-keyboard combination through AR. We will systematically develop this AR-assisted immersive design method to test and apply it for more different architectural structure forms or materials in the early architectural design stage. Promote this immersive design method with convenient manipulation such as UI-based or intuitive gesture-based for architects, get their feedback and opinions after use, and improve the method to make the whole process smooth and reasonable for initial architectural design.

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