HoloBrick: a contextual design and analysis workflow for parametric masonry façade utilizing augmented reality

Yang Song[1], Asterios Agkathidis[2], Richard Koeck[1]

[1] University of Liverpool, Liverpool, UK
yang.song@liverpool.ac.uk; r.koeck@liverpool.ac.ukter
[2] University of Liverpool, Liverpool, UK
a3lab@liverpool.ac.uk

Abstract. This paper presents experimental research about developing a contextual design and analysis workflow utilizing augmented reality (AR) technology to enrich the current design process with an immersive experience. The limitation in the current design process is that due to the lack of spatial perception of the architectural draft on-site preview, designers sometimes find it difficult to fully evaluate their design proposals, which often causes unreasonable design outcomes and incomplete related analysis. To respond to the above problems, the *HoloBrick* research aims to create a unique augmented parametric algorithm for masonry façade designs to develop and validate the proposed contextual AR-assisted design and analysis workflow, which consists of two phases: a) AR contextual design, and b) AR contextual analysis and modification. The research findings highlight the advantages of using AR in the design and analysis process, such as providing immersive preview and interactive input methods, analyzing design outcomes within context, and enhancing draft modifications with better understanding, which are not offered in the current design process.

Keywords: Augmented Reality (AR), Contextual design, Contextual analysis, Masonry façade, Immersive workflow

1 Introduction

Architectural design, being the quintessential 3D-4D design field, has throughout its history, been limited by 2D or cumbersome 3D representation, such as sketching on the plane surface, modelling in design software, or building physical scale models (Barczik, 2018). Even though computer-aided architectural design and modelling software is widely used to produce digital 3D models, their preview is still limited to a 2D-based screen, which lacks an intuitive means of on-site visualization and modification (Song et al., 2022). Additionally, conventional screen-based visualization methods for design and analysis are restrictive to how well the user understands the space on a computer, as the design, analysis, and modification are done outside the building site; hence, there might be disparities between the design and final fabrication (Nguyen and Haeusler, 2014).

The last decade has witnessed the explosion of new technologies, and their impacts have dramatically changed architectural design and analysis 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 to enhance collaboration between designers, digital outcomes, and physical space (Sampaio and Henriques, 2008). AR technology was recently applied in architectural construction fields to augment the current 2D-based construction files into three-dimensional geometries, by its unique visual characteristic of combining real and virtual objects in the aligned physical site (Chu et al., 2020). Besides its application on construction sites, AR technology, with its visual and interactive performance, could potentially augment the conventional architectural design and analysis process (Song et al., 2021). 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 enhanced design draft visualization only. However, due to the insufficient development of immersive technology, as Coppens et al. conclude, very few projects attempt to solve the challenge of modelling and analyzing in an immersive environment, which requires a new design and analysis input and preview methods to eliminate the traditional pen or mouse-keyboard with screen combination (Coppens et al., 2018).

Based on the current research gaps in the existing design method and the possibility brought by the advanced immersive technology, architects began to explore immersive design and analysis to eliminate 2D-based design restrictions. Therefore, seeking a design and analysis method within context can help designers preview, test, and modify design drafts at a real scale on-site and augment the current design experience. This immersive design and analysis method will break through the experience of the conventional design process, stimulate the designers' creativity through contextual holographic preview and interaction, modify and optimize the design draft to get better results according to the on-site building analysis of the design model with contextual environments.

In response to the above existing limitations in the current architectural design and analysis process, this paper aims to develop a contextual design workflow utilizing AR technology to enrich the contemporary design and analysis experience with immersive technology. For this HoloBrick experiment, we utilize AR technology with the parametric design algorithm and building analysis scripts to augment the conventional masonry design methods for façade designs to develop and validate the proposed contextual AR design and analysis workflow.

2 Methodology

The *HoloBrick* research project proposes an augmented contextual design and analysis workflow utilizing AR technology with visual scripting techniques and tests its effectiveness by conducting two experiments with several masonry façade designs with context. The workflow consists of the following phases: **a) AR contextual design**, in which users can design on-site with surrounding contexts through AR, and the interactive design inputs will communicate with parametric algorithms in AR through the screen-based inputs from mobile AR devices (e.g. *iOS* or *Android* smartphones and tablets) or the gesture-based inputs from head-mounted devices (HMD) (e.g. *Microsoft HoloLens 1*); as well as **b) AR contextual analysis**, in which users can preview the design drafts as AR holograms on-site with corresponding daylighting and energy analysis information to modify and optimize the masonry façade design drafts. The task of this research is to use AR immersive technology to realize the parametric masonry façade on-site holographic design, preview, analysis, and modification, which helps designers to fully understand and modify design drafts in an immersive and comprehensive way before the physical construction, and make the design more optimized and reasonable. The above two experiment phases can verify the feasibility and limitations of the proposed workflow multi-dimensionally.

The employed contextual design and analysis workflow (Fig.1) is driven by an instant connection between parametric design software (*Rhinoceros7 / Grasshopper*), AR immersion (*Fologram / Fologram App*) and energy analysis plugins (*Heliotrope / LadyBug*). *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* provides the holographic design drafts and related information on-site preview method, and a user interface (UI) as a bridge to interact and modify the associated parameters in masonry façade design scripts from *Grasshopper* through AR. Moreover, *Heliotrope* and *LadyBug* plugins mainly provide visualized analysis, including daylight and radiation analysis. The *Fologram, Heliotrope,* and *LadyBug* plugins work with its integrated graphical algorithm editor *Grasshoppe*r, which are ubiquitous tools in architectural design, and can easily be integrated into established immersive, contextual design and analysis workflow.

The AR immersion devices for the above experiments are the mobile terminal (*iPhone 14 Pro Max*) and the HMD terminal (*Microsoft HoloLens 1*), which will be used for interactive inputs and holographic design draft and analysis information previews in the contextual design and analysis workflow. 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.

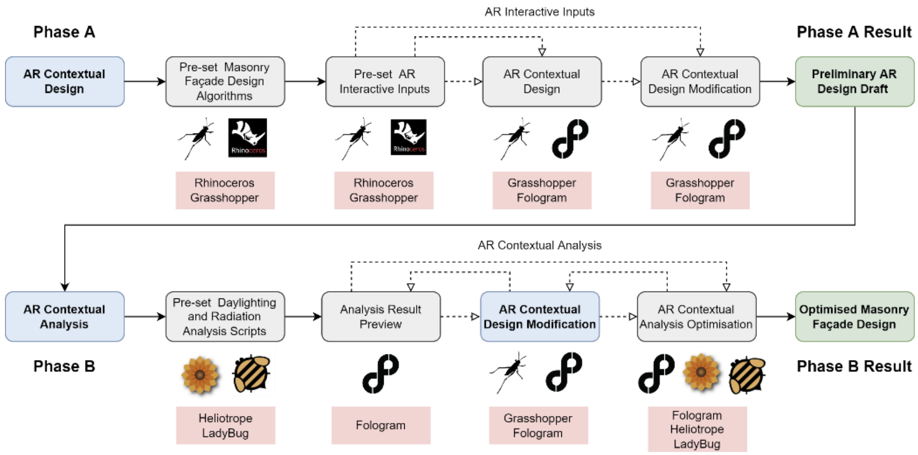

Figure 1. This is the flowchart of the *HoloBrick* research, including Phase A (AR contextual design) and Phase B (AR contextual analysis) (colored in blue); the related plugins for each step (in red); and the outcomes of each phase (in green). Source: Yang Song, 2023**.**

3 Experiments and Findings

3.1 AR Contextual Design

Phase A proposes an AR contextual design method. Compared with the conventional design method, this augmented method enables users to achieve real-time on-site contextual design and draft visualization modifications through UI-based interactions from AR devices. The AR contextual design employed gesture recognition, screen-based interaction, path tracking, and marker tracking to transform intuitive human movements and hand gestures or screen interactions into interactive design inputs for design algorithms through AR. The design algorithms have already been pre-set from the masonry façade design library, representing different parametric structures with related AR interactive design inputs. Users can also customize the design algorithms and AR interventions according to their needs and extract interactive inputs in the open platform, AR UI, through *Grasshopper*.

For example, we use some brick façade design algorithms to validate the AR contextual design method. First, the façade is based on a QR code generated from *Fologram*, which can be measured and placed on-site as the reference point of the façade to locate contextual surroundings with the digital design environment. After scanning the marker through the AR device (*iPhone 14 Pro Max* or *Microsoft HoloLens 1* for this experiment), the design coordinate will be picked up from physical to virtual in *Grasshopper*. Second, the interactive inputs and adjustable values will be extracted from *Grasshopper* and displayed in the AR UI, according to the façade design algorithm. These values shown on the AR UI include brick size, the number of bricks per layer, brick gaps, proportions, brick rotation of each layer, brick patterns, the height and width of the masonry façade, as well as other interactive parametric inputs. Designers can add or modify parameters for their customized algorithms and interventions. Third, according to the selected façade design algorithm, users can start designing their AR masonry façade by developing and adjusting the related parameters through AR UI, previewing and modifying the structure outcomes on-site as holograms overlapping on the contextual surroundings (Fig. 2). Last, the outcomes will be recorded in *Grasshopper*. Multi-designer users can scan the same QR code to access the façade design process and outcomes; as well as remote users can scan and convert the surrounding environment and save them as digital meshes with the same design reference QR code, to scan, share, and modify the design in the same contextual environment, which provides a contextual remote design strategy.

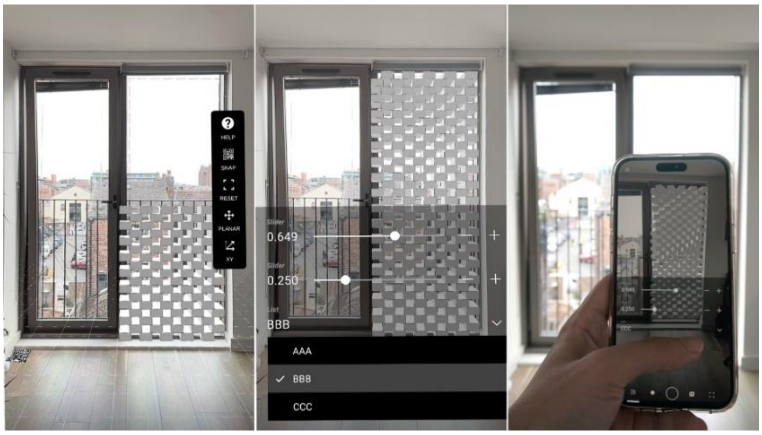

Figure 2. The user is accessing the AR contextual design by scanning the QR code and activating the AR UI. Through the AR UI, the user changes the interactive inputs for designing the façade on-site with contextual environments for better spatial understanding. Source: Yang Song, 2023**.**

In summary, the AR contextual design does fulfill the pre-determined assumptions. We successfully designed various masonry façades with different algorithms in AR UI (Fig. 3). Through the parameter adjustment of the screen-based and gesture-based UI and the real-time on-site preview of the holographic design draft, users can better experience the sense of space and scale, which provides an appropriate and intuitive design experience within contextual surroundings. Ubiquitous AR devices such as smartphones, tablets, and HMDs can be used to activate AR UI for contextual design, which makes this method easier to be popularized and accessible. However, since this is a façade design, the corresponding daylighting and radiation analyses will also be an important part of the design. Therefore, integrating the above analysis results into the existing AR contextual design workflow is considered to be able to give the designer more comprehensive design feedback and contextual inspirations, so as to obtain a more reasonable design result.

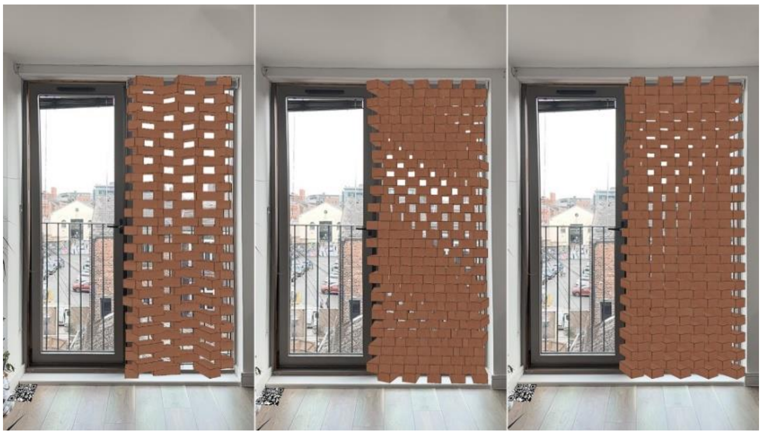

Figure 3. The user is accessing the AR contextual design by scanning the QR code and activating the AR UI. Through the AR UI, the user changes the interactive inputs for designing the façade on-site with contextual environments for better spatial understanding. Source: Yang Song, 2023**.**

3.2 AR Contextual Analysis

Phase B proposes an AR contextual analysis method for the design outcomes from Phase A. Compared with the conventional design analysis method, this augmented method enables users to preview the daylighting and radiation analysis in real-time on-site as AR holograms with the contextual environment from AR devices. The AR contextual analysis employed all the AR features in Phase A into the interactive design algorithms for better modifications through AR. The analysis scripts have already been pre-set for the masonry façade design drafts, including the daylighting analysis with the *Heliotrope* plugin and the radiation analysis with the *LadyBug* plugin with related AR interactive design modification inputs. Users can also customize the other analysis scripts, such as thermal comfort, glare simulation, building energy analysis, etc., and AR design modification interventions according to their needs. The analysis outcomes have to be extracted in the open platform, AR UI, for users to preview and interact with through *Grasshopper.*

For daylighting analysis in this experiment, we use some brick façade designs from Phase A to validate the AR contextual analysis method. First, the user is required to set related location, date, and time information for accurate analysis. For example, we use Liverpool city center as the location in this experiment. To import the related analysis database, the user is required to input 53.4 as "Latitude" and -2.9 as "Longitude" through AR UI. After that, the user can set a specific date with time through AR UI or a range. Second, the façade design is based on a QR code from Phase A. The user needs to scan the QR code to locate the design draft on-site with the contextual environments. Moreover, the user can emphasize "north direction" by screen-based and gesture-based demonstration through AR UI, or just indicate it through the analysis scripts in *Grasshopper*. Third, after the basic setup, the user can preview the daylighting shadows on-site as holograms through the AR device. Last, according to the on-site holographic daylighting analysis results, the designer can change the arrangement or shape of the masonry façade bricks at any time using the AR contextual design method from Phase A to optimize and modify for better design results (Fig. 4).

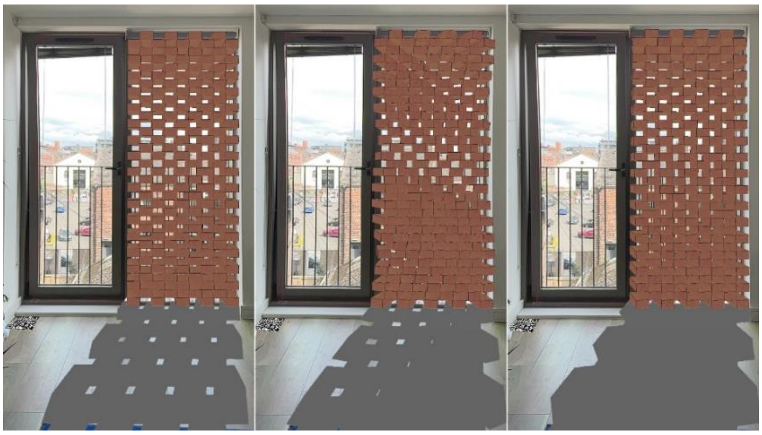

Figure 4. These are the screenshots of the AR contextual analysis from AR UI. Users can preview the daylighting analysis result and modify the design draft in real-time on-site for the optimized design results according to the contextual analysis feedback. Source: Yang Song, 2023**.**

For radiation analysis in this experiment, we use the same brick façade designs with corresponding analysis location, date, and time settings to validate the AR contextual analysis method. Moreover, the user is required to import the related energy plus weather (EPW) file to the analysis script (Liverpool EPW is imported for this experiment). After the basic setup, the user can preview the radiation analysis results on-site as holograms through the AR device. The analysis results will be shown in the color transition of the brick from blue to orange, which means the transition of heat radiation from low to high. Last, according to the on-site holographic radiation analysis results, the designer can modify the arrangement or shape of the masonry façade bricks at any time using the AR contextual design method from Phase A to reduce the heat radiation for better design results, that is, to convert as much orange holographic bricks as possible to blue (Fig. 5).

Figure 5. These are the screenshots of the AR contextual analysis from AR UI. Users can preview the radiation analysis result and modify the design draft in real-time on-site for the optimized design results according to the contextual analysis feedback. Source: Yang Song, 2023**.**

In summary, the AR contextual analysis indeed achieved daylighting and radiation analysis on-site preview. We successfully analyzed various masonry façades from Phase A and modified the design drafts according to better analysis results through AR UI for a masonry façade design proposal (Fig. 6). Through the real-time on-site analysis, users can experience daylight and shadow, and visualize façade radiation, which will help designers modify more optimized solutions based on the above contextual analysis. This immersive analysis feedback design modification is missing in traditional architectural design processes. However, there are limitations and space for further improvement. The AR contextual analysis only carries out limited analysis functions; in the future, more contextual analysis should be developed. Due to the extensive calculation of interactive information transmitted in this prototype, there are delays between holographic analysis preview and design draft interactive modification through AR UI in the entire real-time design and analysis process. Therefore, optimizing the parameters scripts involved or developing customized analysis scripts and plugins will improve the user experience and system fluency. Moreover, the sensors of AR devices are affected by the surrounding light conditions. 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 contextual 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 on-site design context precisely to reduce the unstable disadvantages of current AR.

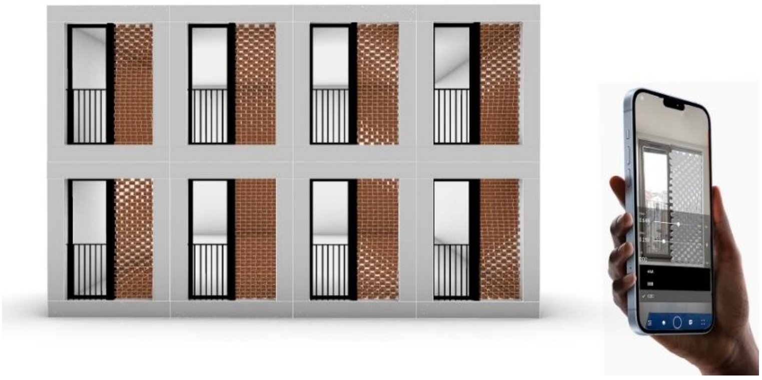

Figure 6. The user successfully designed a masonry façade proposal using AR contextual design and analysis methods through *HoloBrick* research. This AR-assisted contextual design and analysis result-oriented design modification feedback provides users with an unprecedented immersive experience. Source: Yang Song, 2023**.**

4 Conclusion

The *HoloBrick* research developed and verified a contextual design and analysis workflow for parametric masonry façade utilizing AR that successfully applies the customized façade design algorithms with building analysis scripts in AR, exploring a real-time, interactive, and contextual design, analysis, and modification method in the early architectural design stages through the immersive environment on-site. Closely practicing the AR-assisted contextual design and analysis process and outcomes, it can be concluded that the proposed immersive design and analysis workflow does fulfill our pre-determined assumptions and offers a new way to modify design drafts and preview contextual building analysis on-site through AR in real time. The employment of AR technology, with interactive inputs, on-site spatial registration, 1:1 holographic preview, and real-time data interaction features, provided the illusion of actual spatial objects and related information. It aids real-time evaluation and instant modification of design proposals, enables the users to improve their cognition and understanding of space, triggers reflections and remodeling of the architectural design process, and cultivates their design creativity and outcome variety in the early stage. Additionally, traditional architectural proposal analysis is based on screens or drawings. The AR contextual analysis in this experiment can be displayed to users as holograms on-site, providing an immersive and intuitive experience, and helping users to better design based on the analysis results. In addition, architects are able to preview their digital designs with related analysis outcomes out of the sketch or computer screen, as well as interact and communicate with the related on-site physical environment. These on-site design and analysis functions break the conventional 2D-based design method, providing designers with a 3D-4D immersive perception in AR for more practical design.

The AR contextual design and analysis workflow 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. In future research, besides the façade, more architectural element designs and more functional building analyses will be developed and tested. Moreover, we will promote this AR contextual design and analysis workflow 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.

References

Barczik, G. (2018). From Body Movement to Sculpture to Space, employing immersive technologies to design with the whole body. eCAADe 2018, Vol 2, p. 781-788.

Song, Y., Agkathidis, A., & Koeck, R. (2022). Augmented Bricks: an on-site AR immersive design to fabrication framework for masonry structures. In the CDRF 2022, Hybrid Intelligence, Tongji University, Shanghai, China, pp. 385-395.

Nguyen, DD. and Haeusler, MH. (2014). Exploring Immersive Digital Environments, and developing alternative design tools for urban interaction designers. CAADRIA 2014, p. 87-96.

Huang, X.R., White, M. and Burry, M. 2018. "DESIGN GLOBALLY, IMMERSE LOCALLY: A synthetic design approach by integrating agent-based modeling with virtual reality." In CAADRIA 2018, 473-482. Hong Kong.

Sampaio, A.Z. and Henriques, P.G. 2008. "Simulation of construction processes within virtual environments." In the Third International Conference on Computer Graphics Theory and Applications Conference, 326-33. Funchal, Madeira.

Chu, CH., Liao, CJ. and Lin, SC. (2020). Comparing Augmented Reality-Assisted Assembly Functions, a case study on Dongong structure. Applied Sciences, 10, 3383.

Song, Y., Koeck, R. and Luo. S. 2021. "Review and Analysis of Augmented Reality (AR) Literature for Digital Fabrication in Architecture." Automation in Construction, 128 (2021) 103762.

Coppens, A., Mens, T. and Gallas, M.A. 2018. "PARAMETRIC MODELLING WITHIN IMMERSIVE ENVIRONMENTS: Building a bridge between existing tools and virtual reality headsets." In eCAADe 2018, 711-716. Lodz.