A METHODOLOGY FOR MATERIAL-BASED COMPUTATIONAL DESIGN SUPPORTED BY MOBILE AUGMENTED REALITY APPLICATION

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Abstract
To represent design, both physical and digital models are utilized in the process. However, they usually don't function in unison. In order to synchronize these two types of models, the changes made in one model are generally translated into the other one later. This study intends to provide a conceptual framework for a simultaneous and synchronized model for the use of material, structure, and performance in the preliminary design stage. The methodology of the study includes evaluating material attributes, structural systems, and building performance of a physical model in the digital environment by using a Mobile Augmented Reality (MAR) interface. Because the cameras in MAR environment are mobile, the range of views can be expanded, and/or designs can be superimposed on user interfaces virtually. Thus, object interaction and navigation are all made possible. By offering a comprehensive, synchronized, and interactive design environment, where material, structure, and performance factors are incorporated both in physical and digital models, the suggested methodology will potentially aid users' decision-making process.

Keywords
Mobile Augmented Reality (MAR), Material-based Computational Design (MCD), Building Performance

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A METHODOLOGY FOR MATERIAL-BASED COMPUTATIONAL DESIGN SUPPORTED BY MOBILE AUGMENTED REALITY APPLICATION

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ABSTRACT

To represent design, both physical and digital models are utilized in the process. However, they usually don't function in unison. To synchronize these two types of models, the changes made in one model are generally translated into the other one later. This study intends to provide a conceptual framework for a simultaneous and synchronized model for the use of material, structure, and performance in the preliminary design stage. The methodology of the study includes evaluating material attributes, structural systems, and building performance of a physical model in the digital environment by using a Mobile Augmented Reality (MAR) interface. Because the cameras in MAR environment are mobile, the range of views can be expanded, and/or designs can be superimposed on user interfaces virtually. Thus, object interaction and navigation are all made possible. By offering a comprehensive, synchronized, and interactive design environment, where material, structure, and performance factors are incorporated both in physical and digital models, the suggested methodology will potentially aid users’ decision-making process.

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1. INTRODUCTION

Emerging technologies, such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), which can be used in relation to CAAD (Computer Aided Architectural Design) models, can improve the design processes since they expand traditional techniques of design and making. AR and MR technologies are distinct from CAAD in that they can be superimposed on a real environment, which makes the design environment more dynamic and interactive. The most troublesome limitation of CAAD tools is the flat-screen interface's control by a mouse and keyboard. An AR interface, however, can be controlled by hand and body movements in space. Additionally, it offers real-time feedback (Thees, et. al. 2022). While VR and MR systems may demand some costly equipment, the tools utilized for AR applications are freely accessible via mobile devices. Users could examine their designs for a particular environment by using MAR technology to evaluate designs that were simulated in the actual site context. By employing this technique, designers can increase design efficiency (Wang, et. al. 2007). AR technologies make it simple to collaborate, facilitate social interaction, and integrate digital information with mobile computing. Additionally, they gain flexibility in the design process, allowing them to work with multiple digital models and scales.

The disciplines of architecture, urban design, construction, and digital fabrication have begun to apply MAR applications. The implementation of the model in MAR applications and its enhancements enable the investigation of complicated challenges in the architectural design process. Although the target group of architecture students creates and uses digital 3D architectural models, they rarely factor material and structural performance challenges into their design solutions at the early design stage. Their lack of expertise in these domains is the main cause of this. Form, material, and structure are all considered comprehensively in the material-based computational design approach. Material-based Computational Design (MCD) is as a set of computational strategies supporting the integration of form, material and structure through performance analysis and fabrication (Oxman, 2010; Yazici and Tanacan, 2020).

In this study, the employment of MAR applications in MCD enables evaluating and changing material, structural, and performance-related properties without disrupting the physical model. Thus, it is possible to analyze material qualities, structural systems, and building performance comprehensively. A real-time, synchronized, interactive MAR interface enables the perception of non-visible information about a building. By rotating the building, the architecture students can manipulate it as though it were a 3D item using the computer's 2D interface. The purpose of this study is to construct a model at the preliminary design stage based on material, structure, and performance data to enable synchronization via a MAR interface. This would aid architecture students in the design process and help them comprehend design from a broad perspective. The research conducted in the areas of architecture, engineering, and construction (AEC), digital fabrication, MAR, and MCD has led to the study's junction of architectural design and construction.

292 research papers published between 2010 and 2022 are examined for the literature review in ScienceDirect, International Symposium on Augmented Reality, Google Scholar and Cumincad data bases, which includes annual conferences of the Association for Computer Aided Design in Architecture (ACADIA) and its sibling organizations in Europe (ECAADE and CAAD Futures), Asia (CAADRIA), the Middle East (ASCAAD), South America (SIGRADI) and International Journal of Automation and Computing (IJAC). Following the literature review, the methodology for the suggested MAR application model will be introduced (Figure 1).
1.1 Architectural Design and Related Educational Approach

There are productions that do not immediately interfere by designing alongside a model and just utilize a marker (this can be a QR code), rather than directly designing on the model, in the literature review on architectural design and related educational approach such as in the article by Silcock et al. (Silcock, Schnabel, Moleta, & Brown, 2021). In another research, there is no synchronized state, but digital interventions can be made through finished structures (Song, et. al., 2021). A digital model and a MAR application were created by Grasser et al. (2019) for use in architectural design (Figure 2).

Fig.2: Studies undertaken at the intersection of Architectural Design, Architectural Design Education and AR applications.
There is no research on creating a comprehensive design that considers material, structural, and performance perspectives using a physical model related to MAR application in the literature study on architectural design and architectural design education.

1.2 Construction and Related Educational Approach

In the study's construction and related educational approach section, it is examined in the literature that synchronous intervention with the physical model and digital model produced by a BIM program is achievable via a cloud system. However, rather than using tools more readily available to architectural students or ordinary users, "netcore" software and Microsoft Hololens hardware are employed (Lharchi et al., 2020). While these technologies are harder to use than alternatives like Fologram®, Rhinoceros®, and Grasshopper®, they nevertheless enable working in sync with the digital and physical models. Additionally, this structural system did not use criteria like material change, structural analysis, or building performance analysis, which are the goals of current study (Lharchi, Thomsen, & Tamke, 2020). The method of using the Hololens to build an existing design over the same productions of a three-dimensionally modeled structure is shown in the second example. In addition, various technologies are used, including smart gloves and RFID (Radio Frequency Identification). But instead of employing a mass model research, using such wooden sticks at the start of the design process can help focus on the structural system instead. By utilizing predetermined elements in a mobile augmented reality application, the user can construct a structure comprehensively using the material and monitor the behavior of the building (Abe, et al., 2017). The AR application operates directly over a marker in the final example, just as it does in the architectural design section's example. It is only two dimensional and excludes haptic interaction (Turkan, Radkowski, Karabulut-Ilgu, H.Behzadan, & Chen, 2017) (Figure 3).

Fig.3: Studies undertaken at the intersection of Construction, Related Educational Approach and AR.
1.2.1. Digital Fabrication

Numerous examples in Digital Fabrication pertain to the creation of techniques for building intricate structures that have already been three-dimensionally modeled. Due to their 1:1 scale, a head mounted display like the Hololens is typically needed (Jahn, Newnham, Berg, & Beanland, 2018), (Goepel, 2019), (Fazel & Izadi, 2018) (Figure 4).

Fig.4: Studies undertaken at the intersection of Digital Fabrication and AR.

The studies on digital fabrication primarily concentrate on holographic instructions, and they have flaws in their improvisational design methods. Specifically, novice builders are constructing a 3D model by heeding these holographic directions.

The lack of literature is primarily the tactility, followed by convertibility between the materials, according to literature research in the disciplines of architectural design, construction, and related educational approach intersected with MAR applications. The proposal of MAR integrated MCD in the current study enables convertibility and tactility by utilizing a variety of building materials. The fact that MAR applications are useful, practical, and accessible to a wider audience is another justification for their deployment.

In the next part, a mobile augmented reality (MAR) application is proposed to fill a gap in the literature connected to architectural design, construction, and related educational approaches.

2. METHODOLOGY

The study’s methodology entails superimposing three elements—material properties, structural system, and building performance analysis—onto a physical model with a MAR interface to analyze the effects of wind, light, and shadow. The visual prototyping of the model, technological needs, and model parameters were all driven by these three key domains.

The methodology is based on five stages:

1) Definition of the Physical Model: At the beginning of this study, a physical model is required. This model should be translated into a digital model and integrated with Rhinoceros® by pre-identified QR codes on the Fologram® SDK. This enables the user to recognize the object being worked on.
(2) Design of the Graphical User Interface: Three different inputs (material properties, structural analysis, and building performance analysis) are added to this physical model by a mobile augmented reality application interface, and as a result, this analysis appears separately or optionally overlapped on the smart phone screen. Thus, the user can observe the effect of a digital intervention made on the physical model synchronously through simulations. Finally, the user would receive the necessary information from these three visual mockups.

(3) Specification of the Materials: The type, color and texture of the material is required. The material attributes are entered by the user.

(4) Specification of the Structural System: The structural element type should be selected from the interface of MAR application.

(5) Undertaking Building Performance Simulations: Location data, prevailing wind direction and light and shadow analysis is required as an input. The user enters the aforementioned attributes along with the properties of the material and structural system (Figure 5).

2.1. Technological Requirements

The case study prototype of the GUI (Graphical User Interface) is a skeletal construction with horizontal and vertical parts like columns and beams that offers a straightforward structural plan for prototyping. To make the system simpler and more flexible, the flooring is excluded. The Fologram® SDK includes pre-identified QR codes for each type of beam or column. As an illustration, the dimensions of a particular beam or column as modeled in the Rhinoceros®/Grasshopper® environment appear on the screen when the QR code on that beam or column is scanned. The Fologram® SDK is used to provide this object recognition. Because Fologram® includes a motion tracking feature, QR codes are located on the endpoints. It is possible to check if they are positioned horizontally or vertically in the algorithmic modeling environment known as Grasshopper®. Once the modeling and classification of each stick in the Rhinoceros®/Grasshopper® environment have been completed, the application can be launched.

The user-created design and the virtual data overlap when the application is running on the screen. In this program, the user is initially required to enter information for material properties from a list of possibilities, the structural system properties, and finally, information for simulating building performance (Figure 6).

The mobile application will be used and tested in the latter stages of this study. The visual interface prototype is developed in this stage of the study, and a methodology is proposed for the following stages of the investigation.
2.2. Graphical User Interface - Material Specifications

The first set of inputs required pertains to three material attributes. The type of material is one crucial piece of information that the user needs to enter. This could be fundamental building elements like steel, wood, or reinforced concrete. The other data, which should be entered by the user, is the color of the material and the last one is the texture of the material. These three features can be altered directly through the MAR interface without any intervention on the physical model.

On the one hand, the ability to improvise in design is made possible by moving the beams or columns. This makes it possible for a more adaptable working environment. On the other hand, because of the type, color, or texture of the material, material specifications can place limitations on the composition of the design (Figure 7).
2.3. Graphical User Interface – Structural System

The type of the structural element should be entered by searching from the application's library, which includes types of the structural elements, such as steel, wood, and reinforced concrete, like how the material specifications section is performed. For instance, options like I profile and U profile show up if steel is chosen. The dimensions of this structural piece are entered in the subsequent tab. The behavior of the structure, which is modelled on Karamba® and simultaneously sent to the application via the Fologram® SDK, is seen on the MAR application screen (Figure 8).

![Visual Prototyping of the Model II Structural System](image)

Fig.8: Visual Prototyping for Structural System.

2.4. GRAPHICAL USER INTERFACE – BUILDING PERFORMANCE

The building performance interface, which is linked to the Ladybug® and Butterfly® tools for the simulations and simultaneously brought back to the screen, should be filled out with information such as the position and direction of the prevalent wind (Figure 9).

![Visual Prototyping of the Model II Building Performance](image)

Fig.9: Visual Prototyping for Building Performance.
Users can compare these three different forms of data side by side or independently. They can be incorporated into their context and surroundings, and in that environment, simulations tailored to the performance of buildings can be run. This makes it possible to calculate numerous architectural design, construction, and performance factors.

3. CONCLUSIONS

The capabilities of integrated approach are improved by using emerging technologies in architectural design. For instance, CAAD technologies make it possible to see building components accurately using representations like plans, sections, elevations, and 3D models. Data-driven design and material-based computational design have more potentials thanks to emerging technologies like virtual reality, augmented reality, and mixed reality that aid with architectural representation. This technology helps the target group not only visualize the data from the developed models, but it also allows them to interact with the model and improve the design before it is implemented.

3D models can be interacted with in a more flexible setting with AR. The experiment of designing with real and virtual items is enhanced by AR. The creative design process can be improved by experimenting with and changing actual and virtual items together. In addition to being necessary for creative design, data-driven design and material-based computational design are also critical parts of design. As a comprehensive and coordinated design production tool, this decision support system offers to incorporate the material, structure, and performance characteristics of physical and digital models into the design. Compared to 2D paper drawing or utilizing traditional CAAD tools, the architectural design process necessitates more flexible solutions. The decision-making processes in design are successfully supported by haptic and digital interaction, creating a 3D interactive model, and experiencing the digital results in a real-time environment.

Students will be able to gather a variety of data simultaneously and become aware of both the emerging tools and the data that are crucial in the design phase by incorporating this proposed technique into both architectural design and architectural education. Students and professors can also collaborate on designs while using MAR applications.

The visual interface prototype is developed as part of this research. The mobile application will be created and tested in the latter stages of this study. Additionally, future iterations of the technique could incorporate a variety of performances.

An integrated approach to architectural design should be taken into account in future study by concentrating on the contextuality and technology components of working with a physical model and the site condition combined. The context and environment of a building, which have an impact on the building's functionality, form, and materiality, are absent from the current article. Taking this into account at the outset of the design phase enables more overall design. In the future, this might potentially be put to the test by the employers or the professors.

The Graphical User Interface (GUI) and the methodology are the sole components that are designed and offered in this research. Upcoming studies will also examine how the application is used in practice.

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