Enhancing End-User Involvement in the Facilities Design Process using Mobile Augmented Reality

By

Bassam Ashraf Mahmoud Shouman

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfilment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Integrated Engineering Design in Construction Projects

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Under supervision of

Prof. Mohamed Mahdy Marzouk

Professor of Construction Engineering
and Management
Structural Engineering Department
Faculty of Engineering, Cairo University

Prof. Ayman Ahmed Ezzat Othman

Professor of Construction and Project
Management
Architectural Engineering Department.
Faculty of Engineering, British University
in Egypt

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Approved by the Examining Committee:

Prof. Mohamed Mahdy Marzouk .... Thesis Main Advisor
Professor of Construction Engineering and Management – Structural Engineering Department – Cairo University.

Prof. Ayman Ahmed Ezzat Othman .... Thesis Advisor
Professor of Construction and Project Management – Architectural Engineering Department – British University in Egypt.

Prof. Ayman Hassan Ahmed Mahmoud .... Internal Examiner
Professor of Architecture – Architectural Engineering Department – Cairo University.

Prof. Mostafa Refat Ahmed Ismail .... External Examiner
Professor of Architecture – Architectural Engineering Department – Ain Shams University.

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

Engineer's Name: Bassam Ashraf Mahmoud Shouman
Date of Birth: 23/12/1992
Nationality: Egyptian
E-mail: shoumanbassam@gmail.com
Phone: 002-01120646664
Address: Nasr City, Cairo.

Registration Date: 01/10/2016
Awarding Date: / /2019
Degree: Master of Science
Department: Integrated Engineering Design in Construction Projects

Supervisors:

Prof. Mohamed Mahdy Marzouk (Thesis Main Advisor)
Prof. Ayman Ahmed Ezzat Othman – British University in Egypt

Examiners:

Prof. Mohamed Mahdy Marzouk – Cairo University (Thesis Main Advisor)
Prof. Ayman Ahmed Ezzat Othman – British University in Egypt (Thesis Advisor)
Prof. Ayman Hassan Ahmed Mahmoud – Cairo University (Internal Examiner)
Prof. Mostafa Refat Ahmed Ismail – Ain Shams University (External Examiner)

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End-user involvement; Mobile Augmented Reality; interactivity; interactive design projects; facilities design.

Summary:
Mobile augmented reality is one of the advanced 3D representation tools that has been utilized in several industries and specifically in the field of Construction. This research is built up upon exploring the immersive experiences MAR create for end-users which allows them to be part of the design process. In addition, the motives of developing a MAR application is based upon identifying the downsides of end-user involvement approaches that has been classified as co-design and user-centered design. Moreover, through reviewing literature practices in MAR field, an android compatible application is developed which is able to represent design alternatives through dynamic markers were end-users can change wall locations, interior and exterior wall materials thus, creating an immersive end-user experience. In-order to evaluate the impact of MAR, the application is experimented with 33 participants on an actual case study which is British University in Egypt`s Library that is modelled using 3Ds Max, followed by survey questionnaires to gather the required data. Then, the acquired data has been analyzed using SPSS where results indicated that MAR showed a positive impact on enhancing end-user involvement and design understanding of the project. It also allowed them to produce different design alternatives in comparison to the traditional approach were end-users were constrained by the available tools thus, showing low design interaction and understanding. Finally, end-users suggested that for future work, more interactive features will make the application easier to deal with and that professionals should adopt and standardize such ideas in future design projects.

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Bassam Ashraf Mahmoud Shouman
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Nomenclature

2D	2-Dimensional
3D	3-Dimensional
AECO	Architecture, Engineering, Construction, and facility Operations
ANOVA	Analysis of variance
ANCOVA	Analysis of covariance
APK	Android Package
AR	Augmented Reality
AV	Augmented Virtuality
BUE	British University in Egypt
CAD	Computer Aided Design
HMD	Head-Mounted Display
HHD	Hand-held Display
IMU	Inertial Measurement Unit
MAR	Mobile Augmented Reality
MR	Mixed Reality
PD	Participatory Design
QR	Quick Response
RIBA	Royal Institute of British Architects
SAS	Statistical Analysis System
SD	Spatial Display
SDK	Software Development Kit
SPSS	Statistical Package for the Social Sciences
STATA	Statistics and Data
UCD	User-Centered Design
USB	Universal Serial Bus
UI	User Interface
VR	Virtual Reality

Abstract

Mobile Augmented Reality (MAR) is one of the advanced 3D representation tools that is used on a broad scale across many industries such as construction, historical sites and other engineering disciplines. This research is built up upon exploring the capabilities of MAR and the immersive experience it creates for end-users which allows them to interact with any model and be part of the design process. In addition, developing a mobile augmented reality application to engage end-users is based upon identifying common end-user involvement approaches adopted in the design process which is classified as co-design and user-centered design. Moreover, through reviewing literature best practices in mobile augmented reality field, an android compatible application is developed through *Unity*, a game development platform and *Vuforia*, an application development platform. The developed application is capable of representing different design alternatives through dynamic markers were end-users can change wall locations and interior and exterior wall materials as desired. Thus, the application creates an immersive end-user experience that is experimented on an actual case study which is The British University in Egypt`s library that is 3D modelled using 3Ds Max.

In-order to evaluate the impact of mobile augmented reality in relation to the existing co-design tools, the application is experimented with 33 participants in a drawing room where they have the chance to experience the existing co-design tools and the MAR application, followed by survey questionnaires to gather the required quantitative data. In addition, the data acquired is analyzed, evaluated and compared to the current practices that are identified from the Literature. The results acquired indicated that mobile augmented reality shows a positive review towards enhancing end-user Involvement, interaction and better design understanding of project. It also allows end-users to produce different design alternatives in comparison to the traditional approach were end-users are constrained by the tools therefore, showing low design interaction and lack of 3D model understanding. Finally, end-users suggested that for future work, more interactive features would make the application interesting and easier to deal with and for professionals to adopt and standardize the process in design projects.

Chapter 1 : Introduction

1.1. General

Successful construction projects are designed and built to meet end-user needs. Those needs are fulfilled in either the design of form and function of a single space or an entire project. Also, end-user needs are believed to be unique for each project and thus, should be incorporated in the design process to ensure a successful project delivery. In order to capture those needs and convert it into a consistent design, a precise yet systematic approach to end-user involvement is required. Moreover, it is necessary to interpret end-users background, environment and the expected future use of the facility in order to design an approach were end-user needs are included at the right times throughout the design and construction process [1]. In this highlight, Augmented Reality has been proven as a strong platform in the Architecture, Engineering and Construction sector for its ability to superimpose 3D models and information using computer-generated graphics in the physical world [2]. Having the ability to represent Design alternatives in reality, could open up possibilities to enhance the current end-user involvement practices which is the focus of this study. Thus, the research is focused onto the study of the utilizing Augmented Reality technology using mobile devices into enhancing end-user's involvement in the Architectural design process.

1.2. Problem Statement

In construction industry, it is important for the designers to understand client needs and expectations to produce a well-designed building that matches the required level of performance and have a positive impact on end-users. Participatory approaches, especially at early stages of the design process, help designers understand and enforce end-users decisions to avoid disagreements with the design outcomes and reduce changes in the design [3]. In addition, throughout the facility design process, end-users are traditionally involved through two main approaches that include: User-centered design and Co-design. Those two approaches have always been used in early design stages where end-users have the chance to design along with the architect to shape the final building output [3]. However, one of the difficulties of adopting participatory approaches in general is that end-users are not either used to the communication language or the design representations used by architects, which hinders the involvement process as found in [4].

In a research conducted by Norouzi et al. [5], stating that the design process stands as one of the most challenging stages that affects the final building output, where inefficient design communication language to involve end-users is still common. Moreover, the usage of the current Co-design tools and techniques are faced with drawbacks as for initiating a design dialogue with non-expert clients because they are neither able to understand drawings and 3D digital models which the words of this language are, nor familiar with its structure. In another research developed by Visser et al. [6], reporting that the most common end-users involvement strategy in a building design process is approached through co-design which depends on several tools and techniques such as brainstorming sessions, sketching design ideas, developing 2D CAD drawings and 3D digital models, where the need for an innovative tools and solutions to help end-users say, do and make what they dream of is still crucial.

Moreover, Kassem et al. [7] reported that the traditional methods used by architects to communicate design information to end-users and other professionals in the same industry is through computer programs such AutoCAD 2D or paper drawings, while such approach is able to deliver good amount of information, yet it does require a prior level of experience and technical knowledge to understand such information. In addition, the representation of a three-dimensional (3D) project on a paper-based manner is inefficient in terms of time required to collect and represent acquired information, errors occurring between drawings and possible misunderstandings between what is actually conveyed in the 3D model and the technical drawings. Based upon this, it has been argued that non-professionals may have difficulty in understanding technical drawings and could turn out to be impossible without professional support [7]. Therefore, in order to overcome the current end-users involvement obstacles, it could be clearly stated that the need for an enhanced strategy for communicating the design process to involve end-users should be studied.

1.3. Research Objectives

The main objective of this research is to identify the impact of Mobile Augmented Reality on end-user involvement in the design process of an architectural project in-comparison to the existing co-design tools. In order to achieve the main research objective, the following sub-objectives are carried out:

1. Identify current end-user involvement strategies, Augmented Reality potentials and benefits to the Architectural design process.
2. Develop a framework for creating a Mobile Augmented Reality application to enhance end-user involvement in the Architectural design process.
3. Experiment Mobile Augmented Reality application and co-design tools on a case study to evaluate end-user's involvement experiences using both approaches.
4. Analyze the results acquired from Mobile Augmented Reality experimental study and survey questionnaires to conclude the patterns of enhancements towards end-user involvement experiences.

1.4. Research Questions

The research questions are aimed towards examining the following points:

1. What are the latest end-user involvement approaches adopted in the construction industry?
2. What are the limitations of the current participatory approaches?
3. What are the benefits and potentials of MAR in the construction industry?
4. How to develop an interactive MAR application that serves the design process?
5. What is the impact of MAR on end-user`s involvement in comparison to participatory approaches?

1.5. Research Scope and Limitations

The research scope embraces the utilization of Augmented Reality technology in the Architectural profession using mobile devices to enhance the current practices of end-user involvement in the design process. The developed application can be used to simulate a pre-made interior 3D models along with scripts that allow movement of walls, re-allocation of furniture and changing materials of floors, interior and exterior walls to open up possibilities for end-user interaction. However, the research scope is limited to the design process of the architectural profession and does not guarantee that the proposed application could be