Enhancing users involvement in architectural design using mobile augmented reality

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Enhancing users involvement in architectural design using mobile augmented reality

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Abstract

Purpose – Mobile augmented reality (MAR) is one of the advanced three-dimensional (3D) representation tools that has been recently utilized in the construction industry. This paper aims to assess a user’s involvement levels through MAR application that has been experimented against traditional involvement techniques through an existing facility, plan re-designing scenario.

Design/methodology/approach – Through reviewing related literature studies in the MAR field, an application has been developed that can superimpose real design alternatives on paper-based markers, allowing for flexible wall positioning, interior and exterior wall material application. As such, an enhanced user involvement experience is created. To measure user involvement levels, the application is experimented with 33 participants having the British University in Egypt’s library building as a case study, followed by survey questionnaires to gather and evaluate user responses.

Findings – The results of the analyzed data using SPSS indicated that MAR showed a positive impact on enhancing user involvement and better understanding of design projects. It also allowed users to produce different design alternatives in comparison to the traditional involvement approaches where users showed low design interaction and understanding.

Originality/value – The interactive features of the proposed application facilitate implementing ideas in design of construction projects that require user involvement.

Keywords User involvement, Facilities design, Interactive design projects, Mobile augmented reality

Paper type Research paper

1. Introduction

The construction industry is concerned with delivering successful projects that meet users’ needs and fulfil their requirements. Any construction project passes through a series of phases. One of the most important phases in any project is the design phase. Within this phase, the user’s requirements are translated into technical drawings and specifications. In addition, crucial decisions that affect the performance of the building throughout its life cycle are made. Moreover, 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. To capture those needs and convert them into a consistent design, a precise yet systematic approach to user involvement is required. Moreover, it is necessary to interpret the user’s background, environment and the expected future use of the facility to design an approach where user needs are included at the right times throughout the design and construction process (Christiansson et al., 2011). In this highlight, augmented reality (AR) has been proven as a strong platform in the field of architecture, engineering and construction sector for its ability

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to superimpose three-dimensional (3D) models and information using computer-generated
graphics in the physical world (Olsson et al., 2012). Having the ability to represent design
alternatives in real time could open possibilities to enhance the current user involvement
practices, which is the focus of this paper.

Furthermore, in the design process, it is necessary for designers to understand user needs
and expectations to produce a well-designed building that matches the required level of
performance and serve the intentions it was built for. To understand those needs,
participatory approaches, especially at early stages of the design process, help designers
understand and enforce users’ decisions to avoid disagreements with the design outcomes
and reduce changes in the design later on (Caixeta et al., 2013). In addition, throughout the
facility design process, users are normally involved through two main participatory
approaches, which include user-centered design and co-design. Those two participatory
approaches are always adopted in early design stages where users either have their design or
project tailored to their needs through team of professionals from their side, which is the base
of user-centered design, or directly involved in the design process along with professionals to
shape the final building output as in co-design approach (Caixeta et al., 2013). Through
reviewing literature studies, an end-user’s involvement in the design stages of a product has
several benefits: improved quality of the system arising from more accurate user
requirements, no costly feature that users do not want or cannot use, improved level of
acceptance of the system and ultimately improved end-user satisfaction (Kaya, 2004), (Pemsel
et al., 2010). In a research conducted by Justin et al. (LAI et al., 2010), where user-centered
approach has been adopted in design projects, resulted in designers forming a better
understanding of users’ requirements, and hence, they can actively validate design directions
and concepts that serve end-user’s needs. In another research developed by Kylmäläinen and
Siltanen (2014), participants were invited to develop an interactive interior design system,
adopting co-design concepts using augmented reality which allowed the participants to
provide valuable system design information during discussion. The participants also
presented remarks regarding the possibility of true scale of furniture in the system where any
user can easily furnish his apartment using the developed service application, realistic
rendering in terms of lights, furniture scale etc. In a research conducted by Fumagalli et al.
(2020), a case study of a public green space inside the Municipality of Milan that has been co-
designed with end-users and architects is aiming to serve elderly people, resulting in an
enhanced social well-being and active aging spaces that serve elderly people through selected
set of trees, human artifacts, ramps and special elderly walk-ways, social and therapeutic
spaces, playground, etc. Such integration between designers and end-users allowed a better
space for elderly people. However, one of the difficulties of adopting participatory approaches
in general is that users are neither un-familiar to the communication language nor the design
representations used by architects, which hence hinders the involvement process
(Tzortzopoulos et al., 2009).

In a research conducted by Norouzi et al. (2015), highlighting the design process as one of
the most challenging stages that affects the final building output, where inefficient design
communication language to involve 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. Also, in another
research developed by Visser et al. (2005), reporting that the most common user’s 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 innovative tools and
solutions to help users say, do and make what they dream of is still crucial. Moreover, Kassem
et al. (2012) reported that the traditional methods used by architects to communicate design
information to users and other professionals in the same industry is through computer programs such as 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 research claims that graphical representation of project design drawings on a paper-based manner is inefficient for all type of users in terms of the time required to collect information, possible misunderstandings between what is actually has to be conveyed in the 3D model and what is represented on the drawings. Based upon this, it has been argued that non-professionals may have difficulty in understanding project drawings and could turn out to be impossible without professional support (Kassem et al., 2012). Therefore, to overcome the current end-user’s 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.

In previous research studies conducted for user involvement approaches, simple tools and techniques are still being adopted to allow professionals ease user involvement and encourage them to take part in the design process. However, as per author’s knowledge and current literature, the impact of adopting AR techniques using mobile applications to encourage users to participate in the design process has not been examined so far. Therefore, a mobile augmented reality (MAR) application has been developed, which holds the purpose of representing and translating a real project scenario to a 3D model embedded into a mobile application for users to study and develop in real world through special AR platforms. This application has been utilized to validate user experiences and involvement levels against the existing user involvement tools. To compare the level of involvement, a case study of an existing library building has been selected and rendered into an MAR application and compared against existing user involvement tools identified in previous research. The contribution of this study adds detailed assessment of user involvement levels through comparing traditional co-design tools against the proposed MAR approach through the conducted experimental studies and questionnaires. This study also provides guidelines for practitioners on how to develop basic MAR applications as per existing research studies and a stepping stone for further research studies. Also, further research studies could explore the possibilities improving user involvement levels throughout the early stages of the design process using other technological advances such as virtual reality (VR), where real-life project models are studied in a virtual environment or mixed reality (MR), where virtual models overlay real-life objects in an interactive way.

2. Literature review
2.1 User involvement approaches
Users could be generally classified into (1) visitors, who act as temporary occupants as they are not using the facility on a regular basis; (2) occupants, who are defined as people or users who regularly inhibit a facility and use it for a specified purpose as individual occupants; and finally, (3) owners, who actually own the facility and make use of it through renting or actually using it (Othman, 2007). The term user involvement is defined as a need-based attitude toward a project process development such that this project is both important and personally relevant (Kappelman and McLean, 1991). It works by bringing the design team into direct contact with potential users, which in turn encompasses various levels; each level represents the relationship between users and service providers at a different level of power (Kujala, 2010). Those levels are defined as informative, consultative and participative. In informative form, users only provide and receive information, which is the lowest level of involvement. Consultative is the intermediate level, where users are consulted whenever it is needed, and they can make comments on a predefined service or range of facilities. Finally, participative, which is the highest level of involvement, gives higher involvement powers to users in influencing the decisions related to the whole process (Caixeta et al., 2013).
In literature, there are several approaches for user involvement such as user-centered design, participatory design, ethnography and contextual design (Kujala, 2010). In this paper, the literature is focused on two approaches known as user-centered design and user participatory model as they are more specific to the design process (Caixeta et al., 2013). In the user-centered design approach, the project is designed to meet the requirements of users, which implies an important focus on the collection of user data through qualitative and quantitative techniques, and is interpreted by designers in the form of concepts that should benefit to users as a global entity (Fischer et al., 2019; Latortue et al., 2015). At this stage, direct contact with users is crucial to understand the various context of use. On the other hand, in the participatory design, users take an active role by expressing themselves directly and proactively through the design development process. Also, they take part in design meetings and give their opinion on the product, through an iterative dialogue with the designers (Fischer et al., 2019; Latortue et al., 2015). In addition, the participatory design model consists of two sub-categories as follows:

1. Co-creation, refers to the involvement of different stakeholders in various phases of the project aiming to create the desired project outcomes together with the design team from the planning phase, pre-design phase to the implementation phase, post-design phase (Sanders and Stappers, 2014).

2. Co-design, defined as an approach where users, not necessarily experts, are believed to make creative contributions toward the design process, together with the design team, given that they are provided with the appropriate settings and tools to reach an outcome that is made by people to serve their needs (Vaajakallio and Mattelmaki, 2014). Since co-design focuses on the design process, it is referred to as an instance of co-creation (Sanders and Stappers, 2008).

2.2 Co-design tools and techniques

In a research conducted by Lucero et al. (2012), a co-design framework was adopted, which consists of several stages starting from problem identification till the implementation stage. Throughout this process, three main stages are marked as flexible in terms of adopting different co-design strategies and tools that help with ideas generation, concept development, project prototyping and user involvement.

Furthermore, research studies have been made to identify the current tools that are used to support the co-design process; several design research groups within academic institutions, practitioners in consultancies and industrial institutes have explored such tools, techniques and processes by which it can be applied throughout the design process (Sanders and Stappers, 2008). In a research conducted by Sanders (Sanders and Stappers, 2008), a new patient’s room was designed through involving nurses, and for such process to happen, co-design tools such as sketching through colored pencils, markers and collage papers were used to think of the zoning diagram for the new clinic room, and it is in relation to the surrounding zones. On the other hand, other group of nurses in an advanced stage utilized 3D physical models to construct an idea on the arrangements of the furniture, device’s location and the future shape of this room. Several co-design tools were utilized such as physical models, collage papers and drawings. Other tools such as brainstorming sessions, group discussions, questionnaires were utilized as a part of the co-design approach (Lucero et al., 2012). In a recent research conducted by Taoka et al. (2019), experimenting the adoption of new tools that allow users a sense of anonymity for a free and better idea generation in co-design such as “Idea train tool” where each participant has his/her own isolated space and a device sharing ideas anonymously so that participant can share the ideas but not see owner of ideas, and “Hidden Judge,” which is a kind of a setup where each idea has its own isolated workspace in
which only one participant is allowed to enter to offer anonymity. The study findings show that the concept behind those tools allows for higher both objective and perceived creativity in idea generation and increases critical discussion and participants’ perceived performance in idea selection.

2.3 Mobile augmented reality overview and architecture
AR is defined as a system that combines real and virtual world aspects, where virtual contents are registered and represented in real time; such content could hold interactive characteristics (Azuma et al., 2001; Azuma, 1997). In this case, AR stands as the first virtual step beyond the real environment (Segovia et al., 2015). In addition, over the past ten years, mobile devices with high computational power and sensing modules have become affordable and ubiquitous for almost all people. Nowadays, many AR researchers are interested in how to achieve AR on mobile platforms and how to generate 3D models reconstructed from arbitrary environments using these devices (Kim et al., 2018). To understand MAR, it is crucial to understand how it functions and how mobile phones turn AR into a competitive platform.

In literature, a simple MAR application is developed through software platforms, which acts as a base for building any application since it allows the flexibility for 3D model importing and editing, ability to use C# coding for scripts, allows the import and usage of any SDKs and android packages (Karthiga et al., 2018). Such platforms, such as Unity, provide the necessary tools for the creation of interactive 3D contents, effective workspace, testing and editing features for developers to create interactive applications (Kim et al., 2014). Also, the Vuforia AR extension for Unity enables the necessary marker detection and tracking functionality within Unity, thus allowing developers to create MAR applications easily. Moreover, the Unity interface allows better interaction with MAR contents being developed, user interface clarity, creation of virtual buttons, along with an enhanced graphical representation due to Unity’s built-in shader (Kim et al., 2014).

Also, authoring tools such as Vuforia SDK enable the development of AR applications through a coding environment where developers can write the necessary codes that are used to build up the software applications (Herpich et al., 2017). Amin and Govilkar (2015) highlighted in their research that AR SDKs facilitate many components within the MAR application, e.g. target recognition, tracking and 3D content rendering. After building up the necessary coding platform for the MAR application, a 3D model is developed using 3D software such as 3ds Max and exported to the appropriate hand-held display device such as smart mobile phones.

In this stage, a marker target has to be implemented within the MAR database in Unity so that the smartphone camera can recognize and track features that are embedded within; such tracking type is called vision-based tracking (Rabbi and Ullah, 2013). Generally, the use of markers greatly helps accomplish two main tasks such as extracting information from the image and estimating the pose of the tracked objects to help superimpose the 3D content over the target. In addition, markers also provide reliable, easy-to-exploit measurements for the pose estimation (Elbasiouny et al., 2011). After the target has been recognized, the 3D model is registered in real time over it, giving flexibility for the user to interact with the model based upon the developed user-interface in the MAR application (Gül, 2016).

2.4 Mobile augmented reality in architecture and construction
In the field of architecture design, where 3D visualizations and 2D plan designs are a crucial part of communicating design requirements to clients, MAR is utilized where buildings could be designed and superimposed in real sites for users or owners to view. In a research developed by Jun Wang et al. (2014), it featured a 3D model of a residential building that is
presented in site for users to visualize the model, communicate design issues and understand the house-type design. Also, a marker-less AR system was used where the 2D plans of the building was projected as a 3D model and superimposed over the proposed site location so that users could have a clear view on how their project would look like if it is to be built on the site. Moreover, MAR technology was also used to superimpose the interior 3D model of the same building where users could explore, identify and recommend the shape of furniture used, type and shape of materials used and the division of spaces within the house (Wang et al., 2014).

In addition, MAR has shown a great potential in helping users collaborate with architects and owners in ideas generation and development toward an innovative design solution. In a research led by Gül and Halici (Gül and Halici, 2016), users and architects’ behavior patterns in collaborative design using MAR applications have shown an increase in the efficiency of idea generation and design development. Another research developed by Julie Milovanovic (2017) indicated that innovative techniques have taken its place in design such as collaborative design platform, which offers a relevant visualization setting combining a tangible tabletop system and an MAR application, users or owners can place foam mock-ups on the augmented table, and in the meantime, visualize the 3D models of the whole urban area as well as 3D simulations such as wind studies or sun-path shadows, all through a tablet.

In the field of construction, MAR has proven its potentials to integrate GIS mapping and model information along with GPS positioning to overlay un-revealed site infrastructures where workers could safely excavate and perform site works in places where health and safety are an issue. In addition, using such technology to overlay infrastructures allows to avoid potential damages to buried utilities that can cause substantial financial losses to the project and hence delay or even cease other ongoing construction activities (Behzadan and Kamat, 2009). Also, MAR is capable of utilizing the built-in cameras in any smart phone device to read Quick Response codes that have information on 3D models embedded within the scanned code. This code could allow the site engineers to easily scan the assigned Quick Response codes or marker targets by their mobile devices and acquire a detailed step-by-step guide toward the assembly of any construction formwork or even utilize it to get an overview on the construction steps of any phase of a project as a practice of MAR applications (Diaconu et al., 2016). Another research developed by Meza et al. (2015) highlighted that for monitoring and tracking the construction project, AR on tablet PC or mobile is the best option than other 3D models or Gantt chart. They also pointed out that AR has been able to represent that it is possible to visualize and estimate the work that is performed on site in accordance with the proposed schedule of the process.

Moreover, MAR applications have taken further steps in the construction industry by helping construction workers receive a proper training prior to the use of real equipment in the site through 3D model integration and AR display devices (e.g. head-mounted displays). In a research conducted by Xiangyu and Dunston (2007), they developed an AR-based real-world training system (ARTS), in which heavy equipment operator is trained in real construction equipment with virtual materials and targets in a real construction site. The operator trained by the model was simulated with an almost real interaction and sense of existence with visual, auditory or force displays while cutting down the cost of real site operations, conditions and unexpected events.

3. Mobile augmented reality application
MAR application development requires a series of steps to follow to design the application user interface and allow it to run on smartphones such as iPhone, Samsung and many other devices that are built on Android and iOS software. To develop the required application, a 3D
model should be constructed, as shown in Figure 1. In this stage, the 3D model is designed on a modeling program, e.g. 3ds Max that should support standard type of materials and have an export extension format of " . Fbx." This extension works as a 3D model exchange platform between Unity engine and any modeling program.

In addition, an image target has to be developed through a 2D image of any extension type that is uploaded to the Vuforia website, which works by translating the image uploaded into set of features that is exported as a Unity database as shown in Figure 2. Such image features have a star rating from 1 to 5, a five-star rating means fast and accurate target recognition from the device camera, while a one-star rating means slow and inaccurate target recognition. Afterward, the 3D model data should be linked to the Unity engine platform, which has two import features, one labeled as new asset feature, which imports 3D models of the .fbx format, and the other labeled as import package, which imports the image target Unity database. Those two types of assets are linked together by placing the 3D model over the image target. For the application to work, an application key is acquired from Vuforia’s website, which will be specifically used for this application.

Furthermore, after designing the 3D model and image target importing process, a user interface is developed using “C#,” which is a coding language understood by Unity engine.

Figure 1. Represents the 3D model development of the case study in preparation for an MAR application

Figure 2. The 3D model superimposed over the developed marker using Vuforia and Unity
platform. In addition, a series of scripts are designed that perform specific functions set by the developer, which have to be attached to an individual model unit, e.g. a wall unit or a flooring unit. Those scripts could be e.g. moving objects, material changing etc. After assigning the scripts to the 3D model, a linkage between the Unity engine platform and the Android mobile device should be initiated through downloading android studio tool and Java platform. Also, the Unity platform should be switched to the Android platform. After the linkage is found, the mobile device should be turned to developer mode and linked to the laptop where the application is built and run for testing.

Finally, the MAR application main interface is capable of presenting 3D interior augmented model over a specified 2D image target with user interface features that allow users to interact with the interior model, as shown in Figure 3. The developed user interface commands allow users to navigate around the 3D model, re-design space perimeters, changing interior, exterior and floor material through set of buttons found on each side of the application screen.

4. Case study description
To experiment the proposed application in Section 3, British University in Egypt’s library was selected as the case study, where users of this building are asked to participate into the experiment and give them the opportunity to raise their concerns regarding the spatial arrangement of the library’s ground floor and how the internal spaces could have been organized if the project is to be re-designed in another area of the campus through their experiences of this building. The BUE Library, shown in Figure 4, was completed on the April 06, 2015. The ground floor, which is the focus of this study, has an approximate total floor area of 1,353 m², with an average of 275 visitors per day.

As shown in Figure 5, the ground floor is mainly designed to include a lobby, circulation counter, group study area, café corner, interactive rooms, information literacy skills, cultural events room, exhibition area and photocopy facilities.

5. Application experiment
The experiment aims to evaluate the impact of adopting MAR as a co-design tool to ease the process of involvement and user understanding of design project aspects in comparison to the traditional co-design tools. To achieve the experiment aim, a pre-experimental one-group pre-test, post-test study was conducted on a total of 33 academic members, and senior class students participated from the architectural department. Throughout the experiment,
participants are asked to re-design the library ground floor through set of predefined tasks using co-design tools as the pre-test scenario. Afterward, they are introduced to the MAR application and asked to conduct the same tasks where the results are collected and assessed. For both scenarios, the participants are given four tasks to be conducted and are arranged in order as follow, changing interior spaces through wall re-allocation, re-thinking of new materials for interior and exterior wall, and floorings. Also, they are asked to give different spatial arrangements for the group study and reception desk locations. Finally, they are asked to interact and develop understanding of the 3D design of the floor plan.

5.1 Pre-test scenario
Throughout the experiment’s pre-test scenario, using co-design tools, participants started conducting the assigned tasks. In the first task, they started sketching and drawing new wall locations using colored pencils over the 2D images of the ground floor plan, to define the new spaces they think are spatially not connected or should be transferred to another location.

In the second task, participants started representing the materials they wish to change in the re-designing process of this library using different color codes. Participants started
coloring the group study area in yellow and indicated it with MDF material, lecture room in orange and indicated it with carpet material, cafeteria with mauve and indicated it with marble material and finally, the reception area with tiles indicated with marble material, as shown in Figure 6.

In the third task, participants started assigning names indicated with arrows to represent the space changes. For instance, the group study area was replaced with a lecture room as a new proposal and instead of the existing lecture room and the computer lab spaces, a larger group study area was proposed instead. In addition, the cafeteria was swapped with the computer lab and the copy room to separate the traffic flow of library users from the group study area and the cafeteria zone, as shown in Figure 6. In the last task, participants were asked to interact with the given 3D design of the library model from two perspectives and the interior floor plans for the ground and the second floor to develop an understanding of the
whole case study. In this task, participants developed a good understanding of the 3D model as it is commonly used building and prior knowledge of the case already exists and started marking over the paper-based 3D drawing look for more details into the model.

5.2 Post-test scenario
In the second part of the experiment, participants were introduced to MAR and then asked to conduct the same tasks assigned previously, in the post-test scenario but, this time with the help of MAR application. In the first task, participants were asked to change the locations of the walls to develop and design their own spaces from their point of view. Participants started arranging the interior spaces using the “on-screen” finger movements by dragging the required walls from one position to the other, thus creating a semi-closed group study area and the cafeteria’s zone was closed by walls with an access from the group study area to isolate it from the rest of the library. In the second task, participants started to utilize the interactive buttons on the screen to change materials. Throughout the task, participants had the chance to change interior walls material to green color in the study area zone as it helps in stimulating a relaxed and calm environment suitable for studying. Also, the candidate changed the flooring patterns mainly to marble on the left and middle zones and on the left zone near the computer labs, carpet material was used as shown in Figure 7.

Furthermore, participants were also asked in the experiment to use the proposed application to re-arrange the location of the group study area along with the reception desk.
location. The selected sample of work indicated that the participants managed to move the walls and desks of the study area from its original location, which is near the cafeteria, to be near the lecture hall room. In addition, participants also changed the location of the reception desk and chairs to a new location of their own proposal. The selected sample work indicated that participants were able to click and drag over the reception desk and chairs to a new location using the application interface. Also, the candidate required to move the walls from the right position to the left position to create an empty space for the new reception desk allocation, as shown in Figure 7. Finally, participants were asked to develop an understanding of the proposed 3D interior design of the model. During the experiment, participants showed a better understanding of the model as they were able to navigate all around it and look into the floor plans and understand how the spatial connections between each area.

6. Experiment results and discussion

In line with the aim of the experimental study conducted in previous section, the results showed a great potential in understanding the case study using an MAR application in comparison to co-design approach that required lots of tools and drawings to interpret the design and 3D model. Throughout the assigned tasks, participants using co-design tools easily interpreted and modified the ground floor plan walls using sketching. However, participants struggled in the tasks of re-allocating the group study area and the reception desk, where sketching and drawings did not clearly present their ideas as they wished, and it consumed a lot of time. Also, the task for assigning new materials was faced with some hardships where participants just indicated names or preliminary representation of the materials they wished for. Also, it was noted that most of the participants did not care to draw the new assigned furniture or even material shapes and textures.

On the other hand, in the post-test phase, which involved the use of an MAR application, participants showed better design handling, where they performed the assigned tasks easily through the application interface. Throughout the experiment tasks, participants had the opportunity re-design the spaces through the click and drag function and easily transfer the spaces and arrange them in comparison to co-design where they had to draw over the given drawings, which was a time-consuming process. However, the re-allocation command was not stable enough and required a certain handle to the mobile device for it to work. In the second task, participants had the chance to choose from the user interface the materials they wished to see in the re-designing process instantly, rather than just coloring and drawing textures, but they were also constrained by the limited number of material slots offered in the application. Also, participants easily transferred the location of group study area and reception desk to different places away from the cafeteria and high traffic areas. Finally, participants showed a better interaction with the 3D model and floor plans as they were able to study and examine all aspects of the library building from different perspectives.

To sum up, using an MAR application gave the chance for each participant to do their own re-design of the library and how could the spaces be re-arranged if they are to be involved in the design process of any future building in the university campus. On the other hand, the application requires the collaboration of coding team to offer better user interface to ease the involvement process in comparison to the current co-design tools used.

7. Participants survey and data collection

Following the experimental study, the same participants were also asked to take another step forward to strengthen the study results by answering two close-ended survey questionnaires...
that are designed to collect data generated from each experimental task, once by using co-design tools and other using the MAR application. The survey has been divided into five sections, aiming to identify and compare user’s opinion on the complexity of MAR as a co-design approach, flexibility of each approach in interpreting designs and generating solutions. Also, it identifies user’s opinion on their levels of interaction, and finally, it evaluates the two approaches in terms of its reliability, functionality and ease of usability.

To approach the survey aim, and to analyze the data generated from the questionnaires, data acquired from Section 6.2 to Section 6.5 were inserted into SPSS software, and Wilcoxon signed-rank test, a non-parametric test type, was used to draw out conclusions on the improvements made to user’s involvement. To perform the non-parametric Wilcoxon signed-rank test, each question apart from Section 6.1 was marked with an assumed hypothesis that is either rejected or accepted. The basis of evaluating an assumed hypothesis is through Fisher’s $p$-value approach mentioned in Table 1, which depends on a benchmark value of 0.05, which will define whether the assumed null hypothesis can be rejected or not. The less the $p$-value is than 0.05, the more significant it is to reject the proposed null hypothesis and accept the alternative hypothesis, and vice-versa, for values larger than 0.05 (Gaur and Gaur, 2009; Pandis, 2015).

While the $p$-value can inform the reader whether such effect can be accepted or rejected, it will not reveal the size of the effect this study can have if it is to be conducted again elsewhere. Therefore, to strengthen the results significance, effect size testing is combined along with Fisher’s hypothesis $p$-value results (Sullivan and Feinn, 2012). The significance of effect size tests is usually acquired through dividing the z-value distribution acquired from SPSS (Fritz et al., 2011), where “$Z$” is the test statistic result generated by SPSS over “$N$,” which is the total number of observed samples through the conducted experiment multiplied by two (Tomczak and Tomczak, 2014). The effect size scale is based upon Cohen’s guidelines that is defined as 0.1 for small effect, 0.3 for medium effect and 0.5 for large effect (Fritz et al., 2011). Both surveys have been divided into five sections.

| Q | Description | Co-design Mean | MAR Mean | Ranks | $Z$ | $p$ | Effect size $r = \frac{Z}{\sqrt{N}}$
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<td>$-1.657$</td>
<td>0.097</td>
<td>0.20</td>
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<td><strong>Section 2 – Design interpretation</strong></td>
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<tr>
<td>2</td>
<td>Flexibility in interpreting and modifying 3D design models</td>
<td>3.21</td>
<td>4.39</td>
<td>$+22$</td>
<td>$-3.999$</td>
<td>0.00</td>
<td>0.49</td>
</tr>
<tr>
<td>3</td>
<td>Creativity potentials in architectural design</td>
<td>4.09</td>
<td>4.30</td>
<td>$+13$</td>
<td>$-3.307$</td>
<td>0.01</td>
<td>0.40</td>
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<tr>
<td>4</td>
<td>Problem-solving potentials in architectural design</td>
<td>3.42</td>
<td>4.42</td>
<td>$+22$</td>
<td>$-3.835$</td>
<td>0.00</td>
<td>0.47</td>
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<td>5</td>
<td>Communicating design requirements between owner, user and architect</td>
<td>3.42</td>
<td>4.51</td>
<td>$+23$</td>
<td>$-3.735$</td>
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<tr>
<td><strong>Section 3 – Interaction based</strong></td>
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<td>6</td>
<td>Design interaction experiences</td>
<td>3.45</td>
<td>4.51</td>
<td>$+23$</td>
<td>$-4.131$</td>
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<td>0.50</td>
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<td>7</td>
<td>Flexibility to deliver an interactive involvement experience</td>
<td>2.21</td>
<td>4.63</td>
<td>$+31$</td>
<td>$-4.923$</td>
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<td>0.60</td>
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<tr>
<td><strong>Section 4 – Tool’s assessment</strong></td>
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</tr>
<tr>
<td>8</td>
<td>Ease of usability</td>
<td>3.87</td>
<td>3.93</td>
<td>$+13$</td>
<td>$-0.514$</td>
<td>0.607</td>
<td>0.06</td>
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</tbody>
</table>

Table 1. Survey comparison results using co-design tools and MAR application, rated from 1 (lowest) to 5 (highest)
8. Survey results and discussion

The first section of the survey was general for both questionnaires and mainly targeted collecting information on gender, academic rank and age range of participants while also collecting information on user’s general knowledge to the traditional co-design tools approach and the proposed MAR application. The survey results for collecting participants information in both pre- and post-test showed diverse interest from several academic members and students, where three academic staff along with eight assistant lecturers, nine teaching assistants and 13 students showed a greatest interest in the study. In addition, there was a diverse contribution from both genders divided into 25 female participants and eight male participants, which shows a great interest in this experiment. Also, 17 participants checked an age range between 18 and 24 years that generally reflected for students, while 14 participants checked an age range between 25 and 34 for teaching assistants and assistant lecturers and two academic staff age ranged between 35 and 54, with no one above 55 years. On the other hand, participants’ knowledge using MAR as a collaborative involvement approach showed an average response of good and fair. Such results were acquired because of an informative lecture given before the experiment to ensure minimum level of knowledge prior to application usage to acquire reliable results, as shown in Figure 8. Moreover, the assessment of participants knowledge using co-design tools was mainly very good because of the fact that those tools are mainly used in collaborative design workflow where designers or users, use it to present their ideas using pencils, drawings and physical models to understand and interpret the design being developed. This concludes that a user’s general knowledge to the co-design approach was higher than the MAR approach since it is a new field that not many have background or knowledge on it.

The second section of the survey targets approach complexity assessment. As indicated in Table 1, the assumed null hypothesis is that the complexity of using the MAR approach toward user involvement is higher than co-design tools, and the alternative hypothesis has been assumed that the complexity of the MAR approach is lower than co-design tools. From the results indicated in Table 1 – Section 1, the average mean scores for approach complexity are higher in using co-design tools, which recorded a value of 3.30 in comparison to MAR, which scored a mean value of 2.93, which shows a positive indicator toward rejecting the null hypothesis. Moreover, a value of 18 ranks was recorded, which indicates that 18 out of 33 candidates recorded lower values in the MAR survey than that they recorded in the co-design survey, which means that candidates who viewed co-design as a complex approach reviewed

![Figure 8](image-url)

**Figure 8.** End-user’s knowledge to the co-design and MAR approach
MAR as less complex. Finally, a result of ($p = 0.0485$) was recorded that indicates a higher significance to reject the null hypothesis since the $p$-value is less than 0.05. In addition, a ($r = 0.20$) effect size value was concluded, which provides another justification beyond rejecting the null hypothesis since the proposed hypothesis has a low effect size. Thus, it could be concluded from the analyzed results that the null hypothesis has to be rejected, and that using the MAR approach is considered less complex for users to be involved in the design process in comparison to the co-design approach.

The third section of the survey aims to evaluate participants’ opinion on the flexibility of both approaches in design interpretation. As referred in Table 1 – Section 2, the assumed null hypothesis is that MAR has no impact on design interpretation in comparison to co-design tools, while the alternative hypothesis is assumed that MAR has a significant impact on design interpretation in comparison to co-design tools. The results showed high average mean scores in favor for an MAR application with a recorded value of 4.39, 4.30, 4.42, 4.51, respectively, for each question in comparison to values recorded for co-design tools as 3.21, 4.09, 3.42, 3.42, respectively, which justifies a better design interpretation in comparison to co-design tools. Moreover, a total of 80 positive ranks were recorded between the MAR and co-design approach, which explains that there were high number of participants that showed an enhanced design interpretation using the MAR application while answering the same Questions 1 to 4 in both pre- and post-test questionnaires. Furthermore, a result of $p = 0.00, 0.10, 0.00$ and 0.00 was recorded, which indicates a higher significance to reject the null hypothesis since the $p$-value is less than 0.05. Also, to support the $p$-value justification, effect size was calculated using the acquired $Z$ values, resulting in effect size of $r = 0.49, 0.40, 0.47$ and 0.46, which provides further justification beyond rejecting the null hypothesis since it has a high effect size.

In the fourth section of the survey, which assesses an user’s interactions using both approaches, the results yielded a higher mean in favor of MAR, with results of 4.51 and 4.63, respectively, in comparison to the co-design approach, with results of 3.45 and 2.21, respectively, which indicates that MAR is a better medium for design interaction and understanding. For this section, the assumed null hypothesis is that the MAR has no impact on a user’s design interaction experiences in comparison to co-design tools, while the alternative hypothesis was assumed that the MAR application has high impact on a user’s design interaction experiences in comparison to co-design tools. In addition, a total of 54 positive ranks were recorded between the MAR and co-design approach, which explains that participants showed a better design interaction and understanding through the MAR application while answering the same Questions 1 and 2 in both pre- and post-test questionnaires. Also, a result of $p = 0.00$ and 0.00 indicates a very high significance to reject the null hypothesis since the $p$-value is less than 0.05. Finally, effect size results acquired by dividing $Z$ values over a number of participants in both cases resulted in $r = 0.50$ and 0.60, which provides further justification beyond rejecting the null hypothesis since it has a very high effect size, as shown in Table 1 – Section 3.

In the last section of the survey, which assesses the MAR application and co-design tools in terms of its functionality and ease of usability, a null hypothesis has been assigned to this section stating that the MAR application is understood better and handled easily in comparison to co-design tools, while the alternative hypothesis was assumed that co-design tools are understood better and easily dealt with and handled in comparison to MAR application. The test results indicated in Table 1 – Section 4, for comparison between Question 1, Section 5, in both pre- and post-test showed high mean scores of 3.93 in favor of an MAR application assessment, which proves the ease of usage and understanding in comparison to mean scores of 3.87 for co-design tools. Moreover, 13 positive ranks were recorded between the MAR and co-design approach, which explains that participants showed a better understanding of the proposed application while answering the same question in both pre- and post-test questionnaires. Moreover, a result of $p = 0.607$ indicates a very low
significance to reject the null hypothesis since the $p$-value is greater than 0.05. Finally, effect size results acquired by dividing $Z$-values over the number of participants in both survey cases resulted in an effect size of $r = 0.06$, which provides further justification beyond not rejecting the null hypothesis since it has a very low effect size.

In the post-test survey, three extra questions distributed as one question in “Section 4 – Interaction-based” and two questions in “Section 5 – MAR application assessment” were added to further identify participants opinion on the proposed MAR application and also identify the relation between design interactivity levels and improvements to the application user interface; the results were mainly strongly agree and Agree, because of the fact that participants showed an enhanced design interaction through the UI commands that were available. In addition, the more interactive user interface commands are added, the more enhanced are the design interaction experiences. This concludes that a user’s design interaction through the proposed MAR application is related to the amount of UI features available, as concluded in Figure 9.

In a question assessed in the post-test questionnaire, which aimed to assess the functionality of the developed MAR application, the result indicated that 52% of the participants rated the functionality of the developed MAR application to be very good, and 48% of the respondents rated it as good, which indicates that the proposed application functioned as required with no errors or non-functioning command, except on the view orientation required to use the move script for reception desk and group study area chairs, as shown in Figure 10.
In addition, the last post-test questionnaire, which aimed to assess the opinions of the participants in considering MAR application in the design and construction industry as a supplementary or an innovation co-design approach, indicates that 82% of the participants very much recommend that the MAR approach should be implemented along with the co-design approach and tools to enhance user involvement in facilities design process, while 18% somewhat recommend its implementation, as shown in Figure 11.

In Table 2, a user’s general opinions to the impact of MAR on their involvement experiences throughout the experiment were recorded down at the end of each survey. For the

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**MAR Approach complexity**
1. “It is very important to involve clients and users in the project design process and Mobile Augmented Reality allowed the possibility to understand the design in-hand and interact better with the 3D model which opens up a possibility for a better user involvement strategy”
2. “It is very important to involve clients and users in the project design process and Mobile Augmented Reality allowed the possibility to understand the design in-hand and interact better with the 3D model which opens up a possibility for a better user involvement strategy”

**MAR design interpretation**
1. “I was able to focus the mobile onto details I want to see without referring to someone to show it for me. I would not have been able to see the details I want if I was to see it from a 3D model or a screen”
2. “Users usually find it hard to ask for changes and see it happen on spot, this will definitely change the design process and time required”

**MAR interaction based**
1. “A good approach to have a walkthrough inside the designed building and have a chance to change some features of it using simple user interface buttons”
2. “The interaction with the 3D interior model along with the scripts opens up possibilities for better involvement. Such scripts will not be available using co-design tools which puts it behind Mobile Augmented Reality technology”

**MAR application assessment**
1. “A very impressive prototype application for presenting design proposals. If software programmers could work along with Architects, then potentials for amazing design features that serve the Construction industry will be unlimited”
2. “If more interactive buttons could be added to the user-interface, then the 3D model will be easier to modify. In addition, more coding knowledge is required from the Architect to develop a proper user-interface that serves the needs of the users”

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Figure 11. Recommendations of MAR implementation in the construction industry

Table 2. User’s opinion on the impact of MAR application on design involvement
new MAR approach complexity, it has been suggested that if there is no coding and script writing required to be conducted by the architect, then the approach would be easy for architects to use and generate useful design solutions. Moreover, some other participants reviewed that a user’s participation is very crucial for a project to succeed and that the MAR approach will allow for a better design understanding and interaction, which in turn opens up possibilities for better user involvement. However, one of the participants indicated that co-design tools and techniques are already available in hand, and that no extra developments to user involvement approaches would be needed due to technological barriers and resistance from architectural offices to such change, whether it is related to time required for implementation or the expected benefits in return. Also, the cost of adopting such technology might add up to its complexity.

Participants also reviewed the ability of MAR in interpreting design plan and models where they suggested that focusing onto 3D model details and furniture was made easier using the proposed MAR application rather than looking onto 3D shots taken from one or two perspectives. Also, they added up that it was easier to move furniture and re-design some spaces along with its materials than using co-design tools, which show a better design interpretation and involvement. Furthermore, another participant indicated that the MAR application allowed for easier navigation around the 3D model and that accessing the model is easier than getting permission from the architect or even visiting the office to review the design.

In addition, MAR opened up possibilities for an enhanced interaction through the application where participants indicated that using an MAR application is a very good approach to interact with clients and understand their design requirements quickly. Also, they indicated that using the MAR application is a good way to have a walkthrough inside the model and navigate between different alternative through a set of user interfaces, which enhances design interactivity. To add more, the implemented scripts opened up possibilities for an enhanced interaction, and that the co-design approach is limited for the tools available.

Finally, participants stated that more interactive user interface features should be added to the application, which will contribute in a positive way toward the design process, and it is recommended that educational institutes could raise training sessions for MAR to reveal its potentials for young researchers and students to start using it and implement it in the design process. Another participant indicated that using an MAR application opens up possibilities for coordination between different disciplines where building information modeling models could be possibly incorporated within the application.

9. Conclusions and recommendations
Improving a user’s involvement in early stages of facilities’ design process has always been a challenging aspect to most of the architectural design firms due to the impact of users on the final output as facility users. Therefore, an MAR application was developed to aid the user involvement process, which was experimented on an existing case study. This case study had its floor plan design re-designed using the existing co-design tools approach and MAR application where the acquired data through pre- and post-test questionnaires were analyzed using independent Wilcoxon signed-rank test through SPSS software analysis tool. Finally, the results showed noticeable improvements using the proposed MAR application in design interaction, communication and understanding where users could easily manipulate and generate design solutions for an enhanced user involvement in the facilities design process.

Based upon this highlight, it is recommended to develop the existing MAR application user interface where users could use more interactive features such as creating, modifying the shape and type of selected walls, adding more materials and maybe allow for free-hand
Also, the selected case study examined the impact of MAR toward a public building such as library, where project team consists of owner, architect and users. However, the proposed application can be utilized on projects that consist of owners and architects only such as residential buildings or any other project type might yield a different pattern of user involvement. In addition, it is recommended that each co-design tool such as sketching, 3D physical and digital models, 2D CAD drawings could be experimented and evaluated individually to study their true impact on user involvement in comparison to an MAR application.

References


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