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Optimizing Placemaking of Urban Open Spaces Using a Mixed Reality Approach

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1 ABSTRACT

The quality and momentum of urban open spaces are key parameters for assessing the social, economic, and environmental aspects of a city. Public spaces need to be permanently attractive to human activity. Studies presume that the use of mixed reality technologies to create changeable upgrading interactive designs and uses of urban open spaces will encourage people to spend more time outdoors and make public spaces more attractive. This paper provides timely and empirical information to help practitioners and researchers better understand MR technology for architecture and urban design, specifically for open spaces used as recreational, social, and economic spaces. The study included a simulation of a developed plaza with models of mixed reality combined with physical elements of the plaza, taking into account the activities and behaviour of the users of the square. The surveys were conducted in Saad Zagloul Square in Alexandria with different social criteria, activities, and formation. The initial results of using mixed reality for urban development and place-making show its approbation of users and citizens. They also show the possibility of developing the experience in an easier way to reach all citizens by using it directly through their mobile devices. Therefore, the public presence and interaction with public open spaces and with the architectural elements, such as the facades of the surrounding buildings and elements of landscape and hardscape is positively affected. This leads to enriching social cohesion, and economic activity, preserving the environment, and enhancing sustainability through the development and changeable designs of spaces without using any materials, thus reducing the ecological footprint of open public spaces in the short and long term. Further research seeks to validate the results by applying the study on more open spaces in Egypt.

Keywords: Interaction, Dematerialization, Multiuse, Urban Open Spaces, Cyberspace

2 INTRODUCTION

Open urban spaces in the twenty-first century require an exploration of the social and spatial implications of new lifestyles, values, and attitudes toward nature and sustainability, while considering the future city life models and the patterns of urban open spaces it may accommodate. Urban planning in public open spaces is threatened by the increase in “virtual” transactions, that eliminate the need for real social interaction, but this is also a piece of evidence that the use of new communication technologies can increase and enhance the use of open public spaces; This may include participating in the productive side of our hardscapes and landscapes. "Cyberspace can be seen as a vast virtual laboratory for the continuous production of new architectural visions." (Novak, 248) The role of urban public spaces may need to be rethought. The social and cultural values of open space include new attitudes towards nature and architecture. The study aims to reveal new insights into ways to serve both new human needs and the design framework of urban open space structures. And to discuss the new role of mixed reality in architecture and urban design. In order to achieve these objectives, a literature review of the role of cyberspace and mixed reality in architecture and urban design and the tools, techniques, and capabilities of them help apply placemaking principles of urban open spaces. Then a case study is applied in a public plaza with simulated mixed reality models with an on-site observation, and people questionnaires. The research is carried out on Saad Zaghloul Square in Alexandria. The research ends with a discussion of the effect of mixed reality on urban design, the challenges facing mixed reality applications with users, and a new concept for applying mixed reality directly to users in urban design.

3 CURRENT PLACEMAKING OF URBAN OPEN SPACES

Placemaking is an efficient way to improve the quality of different places in a neighborhood, and by extension, the community and region in which those places are located as well. Placemaking is a human-centered approach to planning, designing, and managing public spaces. Placemaking can be used to enhance

all the places that make up a gathering place within a community: streets, sidewalks, parks, buildings, and other public spaces. This promotes human interaction and promotes healthier, social and economic development in communities. Placemaking harnesses the wealth, inspiration, and potential of local communities to create superior public spaces that promote the health, well-being, and economic well-being of people. Placemaking is the process of creating quality places. Places with a strong sense of place are classified as Quality Places. These places are attractive to people and businesses. They are lively, active, unique locations, interesting, visually attractive, and often with creative activities and public art. They are people-friendly, safe, and walkable with a variety of uses. There are some key elements of Quality Places such as mixed-uses, broadband-enabled, multiple transportation options, multiple housing options, preservation of historic structures, community heritage, arts, culture, creativity, recreation, and Green spaces. When these key elements are in place then the result is Quality Places that are safe, connected, welcoming, accessible, comfortable, allow authentic experiences, sociable, quiet -unless they are designed to be otherwise-, and Promote and facilitate civic engagement. Creative placemaking is a more desired prosses in placemaking that creates a more often alluring place. In creative placemaking, partners in the public, private, nonprofit, and community sectors strategically shape the physical and social character of neighborhoods, cities, and regions around arts and cultural activities. Creative placemaking revitalizes public and private spaces, revitalizes structures and cityscapes, improves local business viability and public safety, and brings diverse people together to interact, celebrate, and get inspired. placemaking process has to cope with new technologies and current interests using cyberspace to achieve changeable needs with an almost zero ecological footprint in each change to stay continuously attractive.

4 THE ROLE OF CYBERSPACE IN PLACEMAKING

Fascinated by the possibilities of shaping the world, people have always been looking for tools to convey this process. Cyberspace has become one of those tools. Virtual technologies related to communication technology change the cultural, social, and material contexts of human beings, and thus the ideas of architecture itself. Cyber architecture in cyberspace intends to go through the evolution of architecture, leading to the de-materialisation of architecture. In contrast, cyber architecture in physical space defines what architecture is, giving a limitation or boundary to this definition that justifies its presence in physical space. Although architecture has been dematerialised which could lead to a reduction in material waste, there is a limit. We still need to live in real architecture even as notions of dematerialisation and abstraction can help to produce useful and interesting real architecture. It needs to be a decentralised and expanded reality, not a closed simulated reality, where cyberisation is integrated with real-world activity. The question now is how cyberspace could be realised in physical space. It is the physical components that make cyberspace present. Regarding the confusion between the concepts of space and place, places, in the physical world, are filled not only with artifacts, tools, and representations of our work but also with other people and the signs of their activities. The sense of other people's presence and the ongoing awareness of their activity allow us to structure our own activities. Cyberspace provides a ground for testing and visualising; the physical space provides a ground for realisation.

5 MIXED REALITY IN ARCHITECTURE

Mixed Reality is an emerging technology that is capable of blending physical objects with digital content in an interactive and real-time fashion (Almagor, 2016). A head-mounted MR device can present virtual 3D objects on see-through displays, allowing to observe the virtual world to co-exist in the real world right in front of the user's eyes, which makes it way different than VR technology. MR devices constantly track the surroundings with built-in sensors to locate the user's current position and allow real-time interaction between virtual objects and the physical environment. In addition, The MR device receives inputs primarily through hand gestures and voice recognition. Due to its ability to overlay BIM models on real construction sites, the architecture, and construction industry soon began to explore the Possible uses of MR technology since the first MR device was made commercially available. The ability to visualise architectural designs and construction layouts directly on site has the potential to significantly improve the decision-making efficiency compared with using existing technologies such as VR headsets, mobile devices, or computer screens, thereby accelerating the pace of design, lower rework instances, and engaging customers in a new way. With MR technologies, employees can identify risks earlier and accurately validate designs and install conditions from early-stage design through to construction. In addition, there is a $ 4 M estimated savings per year. It is

about a 14 % decrease in construction costs. (A Forrester Total Economic Impact Study Commissioned By Microsoft, November 2021). Since the early industry adoption of MR technology, a limited number of design firms and contractors performed pilot tests with application uses, but only preliminary demonstrations and reviews have been found. There were no comprehensive reviews on using of MR technology in architecture and urban design for users as a final design, not just in decision-making.

Tools and technologies existing in mixed reality are studied in a way to be used as an essential part of urban design for users and not just as a tool for studying the design process. Also presenting the unique capabilities of mixed reality technologies that help in achieving the key elements of creating quality places in a new, innovative, and renewed way.

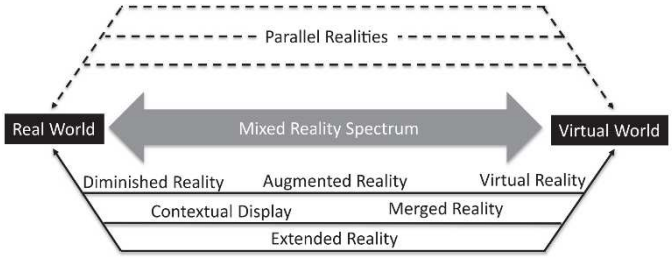

Fig. 1: Mixed-reality spectrum continuum (Bernard C. Kress and Ishan Chatterjee 2020).

5.1 Tools and techniques

To bring mixed reality to site environments, interactivity and safety should be taken into consideration while allowing authentic experience in the space with a sense of engagement. In order to do that some devices were selected to bring MR to the designed spaces. The first commercially available Mixed Reality devices include Microsoft HoloLens and Magic Leap One. Both are stand-alone computer headphones that connect to other devices wirelessly, linking GPS in the HoloLens devices to increase the accuracy of position tracking on site (Xsens, 2018). In addition, Azure Kinect DK is built for mixed reality using AI sensors, or just using the screen of the mobile phone for more broadband enabling. Model format and access MR technology support the most widely used 3D formats in the architecture and construction industry.

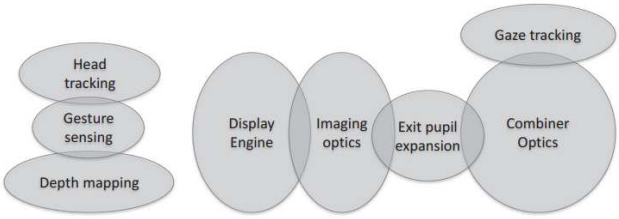

Fig. 2: Functional optical building blocks of an MR system. (Bernard C. Kress and Ishan Chatterjee 2020).

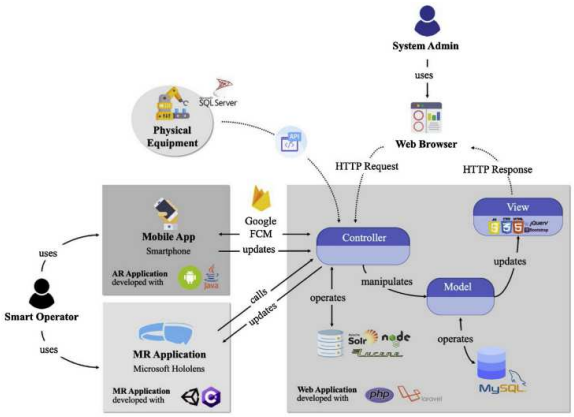

Fig. 3: System architecture (Eleonora Bottani 2021).

For a more detailed technical reference for designers, five MR applications use fbx files as their native file format, which can be exported from a BIM program, which includes Trimble SketchUp, Autodesk Revit, and Autodesk Navisworks, or a 3D modeling program, such as Autodesk 3ds Max and Maya. SketchUp Viewer and Trimble Connect are using SketchUp models as the native file format, and Trimble Connect allows Revit

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model to be uploaded through an add-in. Such devices have the potential to revolutionide how we design, create spaces, work, communicate, travel, learn, teach, shop, and entertain. Already, market analysts show very optimistic expectations of return on investment in MR, for both enterprise and consumer applications. Hardware architectures and technologies for AR and MR have made tremendous progress over the past five years, fueled by recent investment hype in start-ups and accelerated mergers and acquisitions by larger corporations.

5.2 Unique and essential capabilities

5.2.1 Interactive user interface

For designing an accessible and user connected user design, the MR technology provides various interactive features in the user interface to provide a better experience for a different environment, namely the ability to reset, scale, and respond to voice commands. When using an MR device in a large and complex space, MR Builder and Fuzor AR provide a voice command, and immediately brings the menu back right in front of the user's sight.

5.2.2 Immersive view mode

The MR technology enables an unobstructed immersive view mode that allows observation of designed models at their full-size scale on the site, which is unarguably the most essential toolset for architectural and construction uses. Although 3D Viewer is the only MR application that does not provide an immersive view as a native view mode, it can still achieve immersiveness by scaling a model to a 1:1 scale. At such a scale, the user sees the model at its true size and can physically interact and walk around MR models when it is placed on-site or in a large enough space to accommodate the full-size model. By the automatic model alignment technique, a full-size model is allowed to be immediately placed at its correct position on-site after registering the required reference targets. HoloLive 3D requires and Fuzor AR uses the QR code alignment method, requiring a QR code label model component to be inserted in the BIM model first. Then the same QR code label has to be affixed and printed to the same location in the physical space, either a floor or a wall. After using the MR device to scan the affixed QR code label, the model can be immediately aligned. Lastly, some MR applications require pivot points to be selected for fine adjustment of rotation and movement if needed. This helps designers to guide users in the designed space to follow to design flow and to accurately interact with the design features and planned user journey.

5.2.3 Multiuser collaboration

One of the main purposes of using MR in urban design is to bring people to a common real place for socialising and interacting with others in the open space. The MR technology provides the opportunity for multiple MR device users to inspect the same 3D model together through a collaborative session, which is an essential part of decision-making for a project team between the users. A basic multiuser collaboration session starts with a session host whose MR device will upload the model to the sharing service. If other participants want to join the session, the sharing service will download the model to their MR devices for participation. In such a case, all session participants can inspect the same model together, but they do not know where each other is located relative to the model position. For sharing this information, a co-located collaboration session is required where all participants have to determine a common reference point in the physical space to create a shared coordinate system. When the coordinate system is shared across all MR devices in the session, there will be an avatar representing each participant to indicate their position relative to the model, and their focus point will be presented with a laser beam.

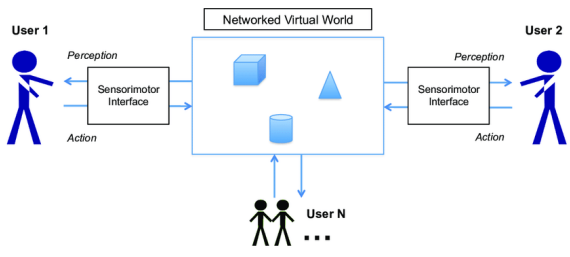

Fig. 4: The conceptual framework of immersive CVE designed for multi-user collaboration. (Weiya Chen 2015).

As shown in Figure 6, the designed model consists of four layers, each layer is affected by the layer below: temporal and spatial coexistence enables awareness of others' activities, which then allows the exchange of opinions and views, the sharing of knowledge and information, and the distribution of operations and work. At the highest level, the final collaboration between multiple actors is enabled by sharing of activities with the balance between assertions and cooperation (negotiation). All these factors with their hierarchy have to be taken into consideration while designing the architectural features and the urban journey for users.

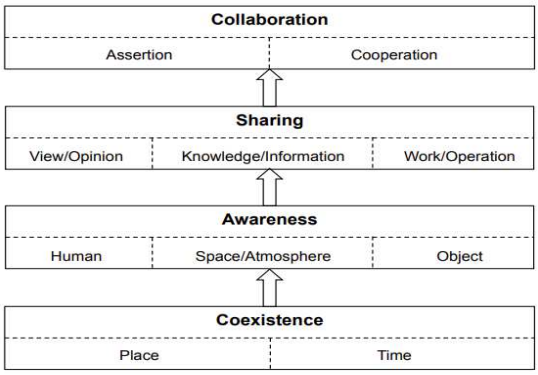

Fig. 5: A hierarchical collaboration model. (Okada 2007).

6 METHODOLOGY

The study aims to reveal the effect of using mixed reality in placemaking urban open spaces and its response from users. The study utilizes many methods to achieve its aim such as on-site observation, user questionnaires, and the use of software programs(3ds Max, Vray, and AutoCAD) to design simulated models in a selected public plaza. To construct the basis for the on-site observation and user questionnaires, a literature review was carried out to reveal the key elements of placemaking and mixed reality techniques discussed in previous research. Data collection is done through handout visitor questionnaires. In some cases, a short interview was held while the user was answering the questionnaire. All questionnaires were filled by the participants while on the plaza for more involvement and relatability to the questions. The questionnaire was formed of questions for users each group of questions refer to a key element of the quality places of placemaking. then these qualities were valued according to the results of the questionnaire. The results from these analyses were then compared with the original plaza qualities.

6.1 Case Study

6.1.1 Site selection and plaza analysis

Saad Zaghloul square is located in Ramleh Station District in Alexandria, Egypt. It is surrounded by Safiya Zaghloul Street, Al-Nabi Daniel Street, Omar Lotfy Street, and El Geish Road. As shown in figure (6) El Raml Station is a neighborhood in Alexandria, Egypt. It features a large public square containing the main station of the Alexandria tramways. It is one of the main centres for tourism, retail, and entertainment in the city. It is helped by the presence of several hotels, restaurants, and entertainment venues. However, huge recreational areas along the seaside caused to loss of the characteristic of the city. Moreover, especially commercial historic entities have lost their functions which caused a deterioration process in historic districts of urban heritage to modern needs. Naturally, citizens tend to choose more liveable and developed areas, so entertainment and commercial dynamics move to more up-to-date places such as shopping malls or just online entertainment or shopping instead of interaction with places and people. This square was chosen for the case study to study the possibility of developing heritage places that express the heritage and culture of the original city using mixed reality techniques to revitalize it while preserving its special character.

As shown in figure (7) the plaza elements were analyzed from main and secondary entrances, circulation paths, and corridors, as well as gathering spots. The main zones of the plaza were also clarified and divided according to their location from being closer to the main path of the commercial part of the city or its attachment to the surrounding buildings, and thus choosing the most appropriate mixed reality transaction for each space.

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Fig. 6: Site analysis of Saad Zaghloul Square (Researcher 2022).

Fig.7: Saad Zaghloul Plaza zoning and circulation Diagram (Researcher 2022).

6.1.2 Participants

All participants in the study were visitors using the plaza. Firstly the Microsoft HoloLens was given to the user after locating him in the QR code position, then The questionnaire was handed out and explained personally to each user. visitors gladly participated in the questionnaire as it was a new experiment, hoping the research would be the future cause of improvement. A total of forty questionnaires were handed out, Five of the forms came back with incomplete answers, rendering them invalid. The final sample was 22 percent females, 51 percent males of different ages, and 27 percent of children.

6.1.3 Applied MR Technique

Some devices were selected to bring MR to the designed plaza to evaluate the use of MR technology in architectural design and urban planning in open spaces through the use of commercially available MR applications in a simulated development of Saad Zaghloul plaza. Microsoft HoloLens and a simulated design in VR goggles were used. Both are self-contained systems that communicate with other devices wirelessly.

GPS in the devices was linked to increase position tracking accuracy on site. Model format and access MR technology were supported by the use of fbx files as their native file format, Using Autodesk 3ds Max and SketchUp as the native file format, and Trimble Connect additionally allows Revit model to be uploaded through an add-in.

Fig. 8: Saad Zaghloul Simulated Mixed Reality Developed Plaza (Researcher 2022).

Fig. 9: Simulated interactive MR development of surrounding facades in Saad Zaghloul Plaza (Researcher 2022).

Mixed reality was exploited to make multiple designs for corridors floors and movable virtual ceilings for spaces, as well as making yards with changing design themes according to the interests of the current time. In addition, mixed reality models were used to re-develop and revive the facades of the buildings surrounding the plaza: either by making them interactive with the movement of users or making a design with a different rhythm using the same proportions of the original facade.

Fig. 10: Site Experiment and users surveys (Researcher 2022).

7 RESULTS AND DISCUSSION

The questionnaire was made to reveal three important topics for the analysis of the mixed reality design for the ability to evaluate and develop it. The first section is about the key elements of quality places and the extent to which they are achieved in the original and proposed MR design of the plaza. This was done by asking users questions about if they find it impressive and recreational, could practice different activities, would come with the whole family, feel safe and comfortable, or would like to open their private business

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nearby, etc. each question scans a key element of the quality places and each question has to be scaled from 1 to 5. As shown in Table 1 the results of evaluating the mixed reality designed plaza were way better according to users.

key elements of Quality Places	New Simulated Designed Plaza Score (1 to 5 Scale)	Original Plaza Score (1 to 5 Scale)
Mixed Use	3.98	1.16
Broadband-Enabled	2.31	3.79
Community Heritage	2.42	2.12
Arts and Culture	2.63	1.25
Creativity	4.19	0.98
Green Spaces	3.79	3.79
Promote and Facilitate Civic Engagement	2.68	1.03
Improves Local Business Viability	3.16	1.21
Cope with New Technologies and Current Interests	4.89	0.00
Safe and Comfortable	1.56	2.76
Sociable and Connected	2.19	2.57
Allowing Authentic Experiences	3.40	2.02
Interaction	3.72	0.84
Overall	3.12	1.80

Table 1: User surveys result on the quality places key elements available in the plaza (Researcher 2022).

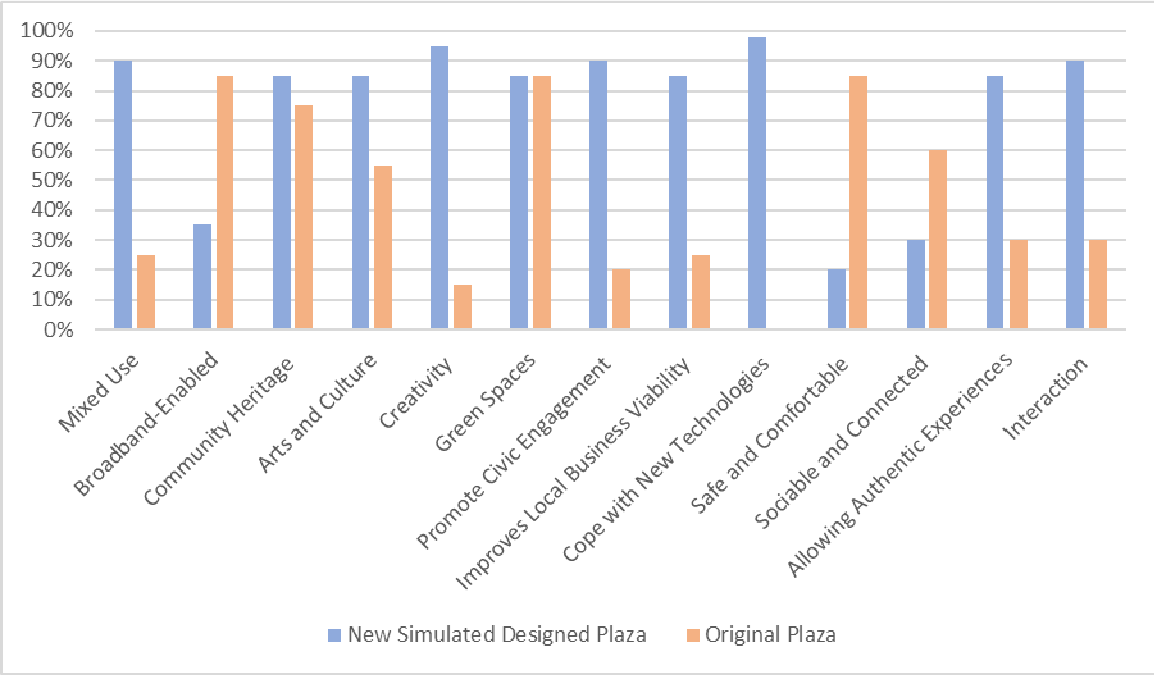

Fig. 11: Chart of the Percentage of quality places key elements available for each design (Researcher 2022).

As for the affecting factors in applying mixed reality in design. Mixed Reality offers many opportunities for architecture and the Urban sector, but also has limitations that determine its actual implementation for users in many aspects, concerning design, environmental, social, and economic factors. The second section of the questionnaire and interviews focuses on the evaluation of these factors and compare the current design and the proposed new one.

	Factors	Mixed Reality Plaza Revival	Physical PlazaRevival
Design Related	Design flexibility	•	○
	Design optimisation	•	•
	Quality issues	○	•
Environment Related	Lower Resources	•	
	Reduced Materials	•	
	Decreasing the Emission of CO2 Less Total Energy	•	○
Social Related	Reducing Workforce	•	
	Jobs Shifting Paradigm		
	Safety	○	•
	New job opportunities	•	
Economic Related	Low Initial Cost	•	
	Reducing Materials Cost	•	
	Reducing Labour Cost	•	
	Cost-reducing	•	
	Unique Architecture	•	○
	Time-saving	•	

Table 2: User surveys result on the affecting factors (Researcher 2022). •: Factor Fully Present, o:Factor Partially Present

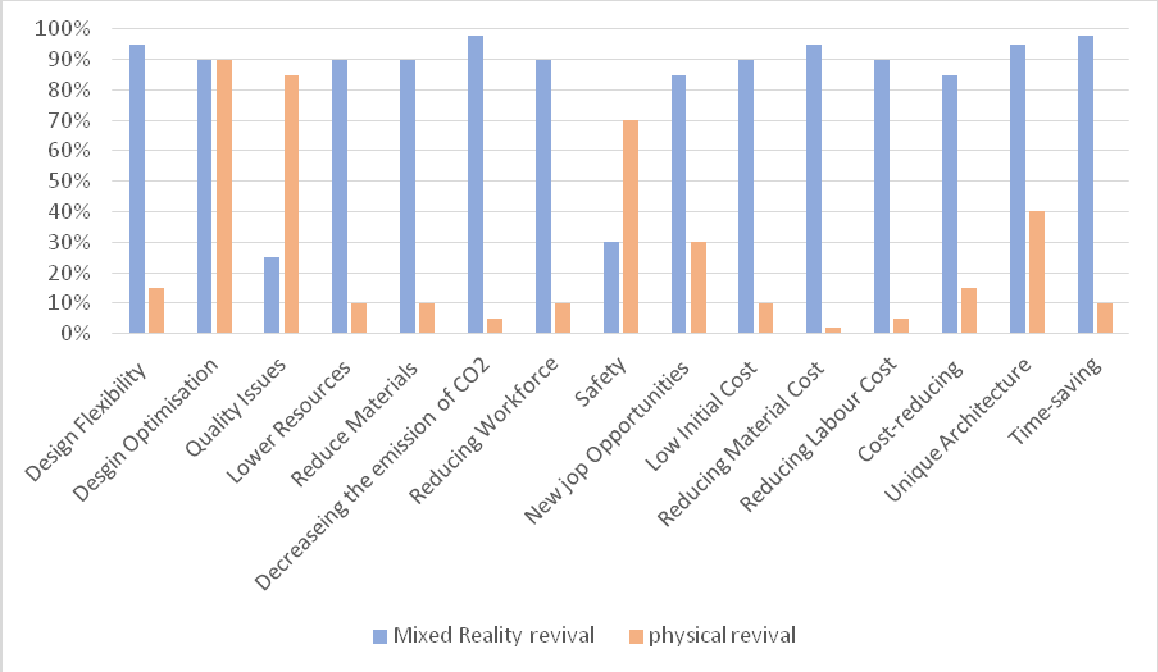

Fig. 12: Chart of the affecting factors of MR on the site (Researcher 2022).

The third section of the analysis depends on presenting the possibilities and challenges of applying this type of design to open public spaces in Egypt o reveal its validity, taking the case study as one example that can be replicated, developed, and adapted to different plazas in the rest of the country.

More than 80% of the plaza visitors received a good user experience evaluation. According to participants' ages the experience was more engaging and attractive for younger ages, which makes sense given the younger generations are more used to connecting to technology and digital interfaces they are more familiar with. older participants were less comfortable and recognizable to new technologies and tools. The site survey also indicated that all users welcome the development of the plaza with different perceptions of development. Older users were less reactive to technological elements but they welcomed that the development was inviting new generations in while maintaining greenery and open areas, as the experience provides for the dematerialised designs of hardscape as well as other urban open spaces elements.

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potentials	challenges
- Multi-designed mixed-used spaces - Increased design flexibility - Time-saving - Ability to use in existing sites - Reducing the current gap between community heritage and coping with New technologies and current interests - Reduced resources and material waste - Reducing the Ecological footprint of urban design - Changeable and upgrading designs - Cost reduction - Reduced workforces and their transportation costs - Opportunities for architects and urban designers to test and apply new innovative designs to users. - Also a free broader opportunity for architecture schools and competitions for multiple unlimited designs according to recent interests.	- Lack of knowledge about technology among the stakeholders - Mixed Reality requires new skills from designers (Designing, operating, control, and Locating in site) - Shortage of tools of mixed reality according to the economic situation of the city. - Lack of Knowledge from users of new technologies - The need of providing more common and public tools to bring mixed reality designs to the public. - The designs could be switched off at any moment so only the physically designed base would be existing.

Table 3: List of potentials and challenges of Mixed Reality design (Researcher 2022).

8 CONCLUSION

This paper provides timely and empirical information to help urban designers and stakeholders better understand MR technology for architecture and urban design, specifically for open spaces used as recreational, social, and economic spaces. The study included a simulation of a developed plaza with models of mixed reality combined with physical elements of the plaza, taking into account the activities and behaviour of the users of the square. The surveys were conducted in Saad Zagloul Square in Alexandria with different social criteria, activities, and formation. The results were analyzed to reveal the validity of using mixed reality for urban development and place-making for users and citizens of Egypt and it shows its approbation with some development according to the economic and cultural situation of the country. They also show the possibility and need of developing the experience in a more simple way to reach all citizens by using it directly through their mobile devices and more public and affordable or free tools like moving screens existing in the plaza for all the public. The study clarified that using Mixed Reality designs in urban open spaces enhances public presence and interaction with public open spaces and with the architectural elements, such as the facades of the surrounding buildings and elements of landscape and hardscape positively affected. Also enriches social cohesion, and economic activity, preserving the environment, and enhancing sustainability through the development and changeable designs of spaces without using any materials, thus reducing the ecological footprint of open public spaces in the short and long term. The design of open spaces is essential for the urban environment, and an understanding of the broad scope of mixed reality in these spaces will help design spaces that encourage public use in different seasons, occasions, and trends for different periods suitable for all age groups with different interests and changing modern uses of spaces leading to improved greatly their ability to live.

9 REFERENCES

Yilei Huang: Evaluating mixed reality technology for architectural design and construction layout, USA, 2020.

Almagor A: Mixed Reality for the AEC Industry: Extending Trimble's Product Capabilities with Microsoft HoloLens, 2016.

Alsafouri S, Ayer SK: A Step-By-Step Procedure for Implementing Mixed Reality Visualization Interfaces in Design and Constructability Review Sessions. Vienna, Heraklion, Greece, 2017.

Alsafouri S, Ayer SK: Leveraging Mobile Augmented Reality Devices for Enabling Specific Human Behaviors in Design and Constructability Review, 2019.

Amira Mohamed Said Ammar, Author: PROSPEC PROSPECTS OF W ALKABILI WALKABILITY IN CI Y IN CITY NEIGHBORHOODSCASE Y NEIGHBORHOODSCASE STUDY: THE CI Y: THE CITY CENTER OF ALEXANDRIA TER OF ALEXANDRIA, Egypt, 2018.

Forrester Consulting Total Economic Impact™ Checklist Commissioned By Microsoft: Planning For Adoption Success Of Mixed Reality Using Microsoft HoloLens 2, 2021.

Eleonora Bottani, Francesco Longo, Letizia Nicoletti, Antonio Padovano, Giovanni Paolo Carlo Tancredi, Letizia Tebaldi, Marco Vetranoc, Giuseppe Vignali: Wearable and interactive mixed reality solutions for fault diagnosis and assistance in manufacturing systems: Implementation and testing in an aseptic bottling line, Italy, 2021.

Bernard C. Kress* and Ishan Chatterjee: Waveguide combiners for mixed reality headsets: a nanophotonics design perspective, Nanophotonics 2021; 10(1): 41–74, 2020.

Bangor, A., Kortum, P., Miller: Determining what individual SUS scores mean: adding an adjective rating scale., Usability Stud. 4 (3), 114–123, Retrieved from https://uxpajournal.org/wp-content/uploads/sites/8/pdf/JUS Bangor May2009.pdf, 2009.
Bernard C. Kress and Ishan Chatterjee: Waveguide combiners for mixed reality headsets: a nanophotonics design perspective Nanophotonics 2021; 10(1): 41–74, 2020.
W. S. Colburn and B. J. Chang: Holographic combiners for head-up displays, " Tech Report No. AFAL-TR-77-110, 1977.
B. Kress: Diffractive and holographic optics as optical combiners in head-mounted displays in Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing – Ubicomp'13, 2013, pp. 1479–1482.
Lee, J., Cameron, I., Hassall: Improving process safety: what roles for Digitalization and Industry, af. Environ. Prot. 132, 325–339.
Roger Lee: Applied Computing and Information Technology, Volume 788.
De Crescenzio, F., Fantini, M., Persiani, F., Di Stefano, L.: Augmented reality for aircraft maintenance training and operations support. IEEE Comput. Graph. Appl. 31, 96–101, 2011.
Understanding Virtual Reality, Interface, Application, and Design, A volume in The Morgan Kaufmann Series in Computer Graphics, 2003.
Adams, Ernest: Postmodernism and the Three Types of Immersion. Gamasutra. Retrieved 2007-12-26, 2004.
M. A. Golub, A. A. Friesem, and L. Eisen: Bragg properties of efficient surface relief gratings in the resonance domain, Optic Commun., vol. 235, pp. 261–267, 2004.
https://www.lighttrans.com/applications/virtual-mixed reality/waveguide-huds.html, sited in june 2022 .
M. W. Farn: Binary gratings with increased efficiency, Appl. Opt., vol. 31, no. 22, pp. 4453–4458, 1992.

ISBN 978-3-9504945-1-8. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER