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RESEARCH ARTICLE

SCIENTIFIC IMPACT OF ARCHITECTURAL INDOOR AUGMENTED REALITY 3D DIGITAL REPRESENTATIONS

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Abstract

This paper focuses on the scientific impact of 3D digital spatial representations in indoor architectural buildings via Augmented Reality (AR) techniques. These 3D spatial representations refer to both changes of proposed structures, design and collaboration process, guiding visitors' experiences, simulations of interdisciplinary information, as well as architectural design, building geometry and modeling process in AR environment. It analyses only the scientific impact of these 3D representations aspects, highlights the innovative representation aspects and quotes main limitations and perspectives.

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Introduction:-

During the last decade, Augmented Reality (AR) become a powerful tool, as an advanced technology, for building designers, allowing interactions among people, computer, and reality, permitting digital and physical objects to coexist and finally providing an intuitive sense of how it might feel like to live in a virtual augmented animated environment (Zhao et al, 2019). 3D digital spatial representations provide real-time precious feedback information since architectural building conception, design and functionality, as well as indoor comfort conditions have a huge influence on the quality of people's well-being (Natephraa and Motamedib, 2019a) by using simulations of spatial elements and descriptive forms (Kouzeleas, 2008) with interdisciplinary approaches.

Many AR 3D simulation systems use different interdisciplinary approaches and techniques with advantages and limitations that must be adapted to the specific conditions and needs of each study. These techniques concern, among others, 3D volumetric reconstruction voxels optimization, building management system incorporation with spatial and texture information capture (Aftab et al, 2018), real-time monitoring of indoor comfort conditions (Natephraa and Motamedib, 2019b), point cloud and sensor data integration and visualization analysis (Stojanovic et al, 2019), sensors and library of speech and gesture recognition tasks (Malkawi and Srinivasan, 2004), etc.

The complexity of these interdisciplinary approaches and techniques in AR environment presents a multifaceted scientific impact compared to the corresponding impact of the "traditional" techniques use of 3D spatial representations, such as CAD, GIS, Video, spatial multimedia representations, etc.

Scientific impact:-

Augmented Reality can extend a project's 4D scheduling and site logistics planning to the project site. Mobile AR (MAR) applications may superimpose virtual objects onto paper plans or directly overlay virtual objects on site in

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order to (a) communicate the behavior of dynamic components on site and (b) detect potential clashes of equipment with real-world elements (Abboud, 2013).

Current AR simulation systems implemented in many scientific fields, such as Architecture, Design process, Construction, Comfort conditions and Energy, Acoustics, etc., impact drastically on scientific processes and interdisciplinary correlations by facilitating simultaneously scientific conception and perception. Some major scientific impacts of architectural indoor augmented reality 3D representations, are summarized in categorizations (Fig. 1).

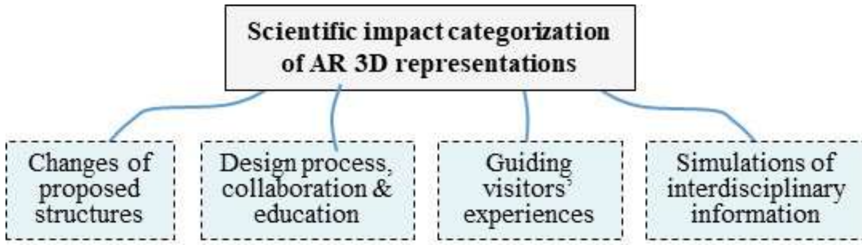

Fig 1:- Major scientific impacts of architectural indoor augmented reality 3D representations.

Changes of proposed structures

AR 3D representations allow experience simulation of changes not only of proposed structures and physicalconditions (e.g. pollution, noise, etc.), but also of full-scale design models simultaneously on different geographical sites (Sorensen, 2006) and impact evaluation of full-scale design (Chan et al, 1999;Tredinnick et al, 2006). This experience of projects with free movements in full scale proposed solutions supports, inter alia, interior design, building refurbishment or construction management and displays virtual data on the physical space, including walls, floors, desks or real objects (Raskar et al, 1998) with deletion of understanding scale and plan orientation problems (Sorensen, 2006).

The use of indoor AR 3D representations tools does not require any previous projects representations knowledge or training requirements with immediate assessment of solutions (Sorensen, 2006). The setup of the entire intelligent system for construction worksite engineers and unskilled novice is easy and improves the quality of the construction worksite, while places construction materials / equipment and hands devices (Wang, 2007). AR 3D representations allow a construction site layout optimization by showing the behavior of dynamic components (devices movements, possible crashes detection with the environment, etc.) (Wang, 2007).

During the design phase, Smart-Device-Based Augmented Reality (SDAR) systems are suitable for on-site AR, by integrating information technology for building refurbishment (Donath et al, 2001;Yusuke et al, 2016), building management and construction(Soyoung and Choi, 2004) or future project's visualization (Moloney, 2007; Chung, 2009). Linking Building Information Modeling (BIM) and AR is also an alternative way to represent technical data on a smart device, facilitating discussions between professionals and citizens (Vaai et al, 2014;Krakhofer and Kaftan, 2015).During construction, BIM data may be geo-located directly on the construction site using MAR in order to communicate project information (O'Brien and Dharmapalan, 2018). MAR can provide 3D registered instructions onto physical components in order to provide task support for assembly construction processes (Regenbrecht and Baratoff, 2005).MAR applications can interface with the real-world construction site and the project management system, allowing users to complete construction reports, check site progress directly in the "field" (Ahonen,2012)and finally aid users to navigate real world building sites during Construction and Post-Completion (Ahonen,2012).

During the Post-Completion phase MAR applications can impact the testing, assessment, inspection and review of a building's performance by (a) assisting users to carry out complex repair and maintenance tasks on building systems and (b) combining a building's Facilities Management System (FMS) with BIM and allowing building users to monitor and plan for ongoing maintenance requirements (Ahonen, 2012). Finally, AR applications can evaluate designs in terms of spatial sequence, multiple viewpoints and perceptual change over time due to the rhythms of environmental and occupancy cycles (Moloney,2007).

The following schema summarizes AR 3D representations impact to proposed architectural structure performance and management during the design phase as well as the post-Completion phase (Fig. 2).

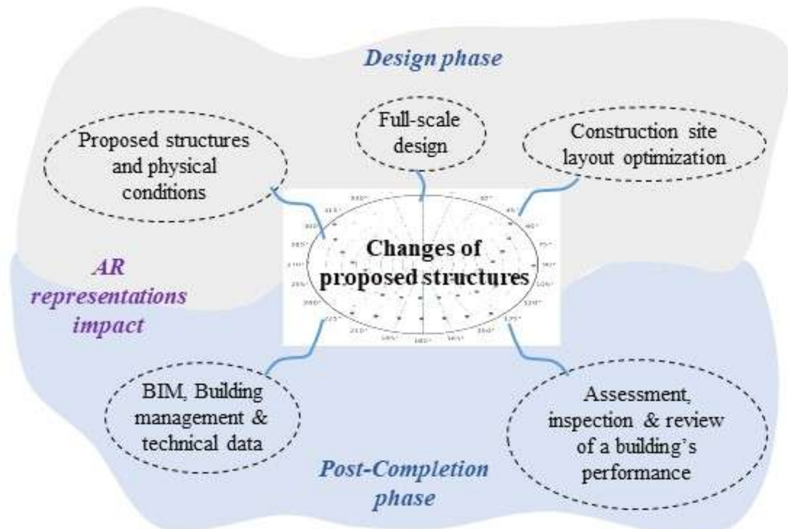

Fig 2:-Scientific impact of AR 3D representations in "Changes of proposed structures" categorization.

Design process

Manipulation of virtual environments during the design process offering better spatial perception (Milovanovic et al, 2017). Designers working with VRAD (Virtual Reality Aided Design) tools have many advantages during the design process, such as creativity enrichment, contextualization of design outcomes, change of virtual model's scale and explicitness of virtual representations end user's integration in the design (Fuchs et al, 2011)and immersive ideation and synchronous collocated or remote design (Dorta, 2007; Dorta et al, 2014).AR systems facilitate design efficiency and collaboration by using, inter-alia, see- through HMD glasses, placeholder objects (PHO), pointers, gestures recognition sensors, etc. (Penn et al, 2004). These features contribute to decision-making thanks to the visualization of alternatives solution and dynamic simulations (Fatah gen Schieck, 2004).

MAR applications influence future design review processes by expanding the media from which designers draw to make design decisions. Although designers are increasingly gaining access to 3D point cloud scans of a site early in the design process, most of the information needed to understand a site's constraints and assess its merit is typically modeled from scratch by the design team (Ahonen,2012).

The following schema summarizesAR 3D representations impact to design process during the design phase (Fig. 3).

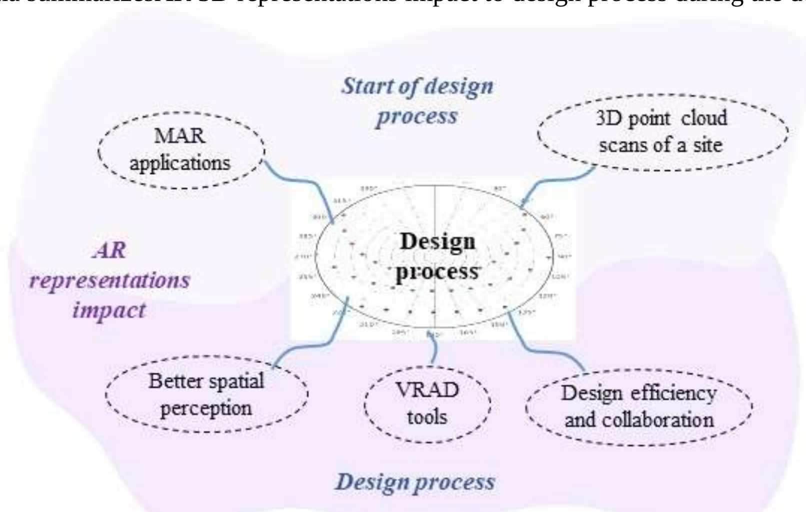

Fig 3:-Scientific impact of AR 3D representations in "Design process" categorization

Guiding visitors' experiences

Guiding visitors' experiences relate, inter alia, to art museums, stationary multimedia kiosks (Sylaiou et al, 2008; 2010), wearable displays such as Google Glass (Leue, 2015; Rhodes et al, 2014), reflective mirrors (Plasencia et al, 2014), projections on objects (Bimber et al, 2006; Karnik et al, 2012; Yoon et al, 2012; Yoon and Wang, 2014), and handheld devices (Damala et al, 2008; Lu et al, 2014; Pierdicca et al, 2015).

MAR applications communicate architectural narrative by overlaying information otherwise inaccessible to the viewer onto a building or architectural detail. MAR cultural heritage applications overlay virtual reconstructions of ancient thriving onto declining historic sites. AR, as a non-invasive technique, allows users to engage with historic artifacts without touching or corrupting them (AR[t], 2013).

The following schema summarizes AR 3D representations impact to Guiding visitors' experiences, mainly in architecture, art and cultural heritage (Fig.4).

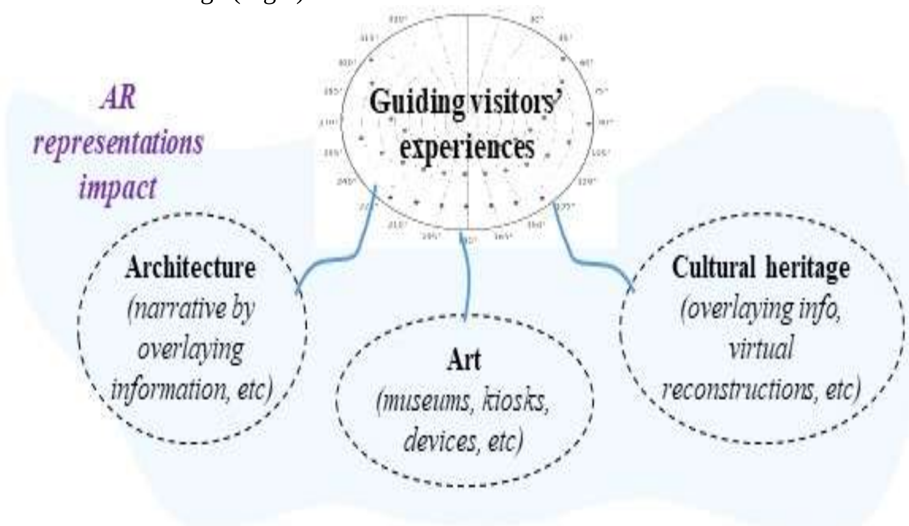

Fig 4:-Scientific impact of AR 3D representations in "Guiding visitors' experiences" categorization.

Simulations of interdisciplinary information

The value-add of AR is in communicating information that other media cannot. AR uses overlay of 4D content (information with a time component) onto physical brackets, such as shadow studies, traffic and wind flows, etc. MAR is not limited to the visual sense, as it can draw on other senses to communicate elements of a scheme, such as the acoustics within a space (Ahonen,2012).

AR enables overlaying time-sensitive virtual data onto physical drawings or models. An augmented content may switch between the structural, mechanical, and hydraulic systems proposed for a building, while retaining the same plan reference (Ahonen,2012). Thus, viewers can appreciate more the orientation of virtual content when a physical drawing or model acts as a reference point. Navigational applications pair AR with GIS data, overlaying visual cues onto real city-scapes to direct users to specific sites (Abboud, 2013).

AR is also used for interior furniture layout planning (Billinghurst, 2001) and manufacturing planning (Doil et al, 2003).AR helps users notice details that would otherwise have been missed. Learning can even lead to a sense of excitement and joy in exploring hidden aspects in the paintings. The excitement has also been noted in other AR studies in museum contexts (Hsi, 2002; Leue et al, 2015).AR enables multiple aspects of social and educational impacts which are not the subject of this study(Aitamurto et al, 2018).

The following schema summarizes AR 3D representations impact to simulations of interdisciplinary information (Fig.5).

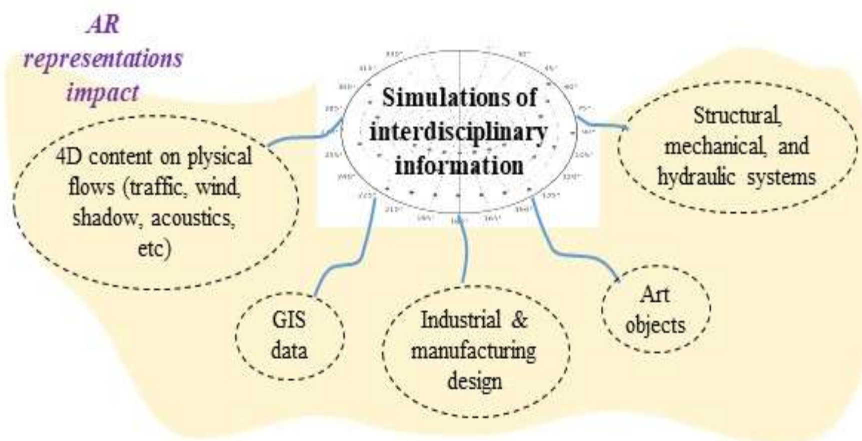

Fig 5:-Scientific impact of AR 3D representations in "Simulations of interdisciplinary information" categorization.

Limitations:-

The main limitations concern technological, financial and behavioral challenges. The technological limitations have to do with devices constrains such as placements, movements and alignments accuracy of the virtual elements in the AR scene, longevity, visual realism and tracking types, etc. (Aitamurto et al, 2018). The financial limitations have mainly to do with costs of hardware purchase and licensing or development apps for AR platforms (Abboud, 2013). The behavioral constraints have to do with AR devices use and operational approaches of switching between the three fields of vision: art, the screen, and the wall labels (Aitamurto et al, 2018).

Scientific impact categorization analysis:-

The scientific, social and educational impacts form the total impact effects of architectural indoor AR 3D simulations which is the content of an imminent publication.

Thus, the scientific impact of architectural indoor Augmented Reality 3D digital representations is not the only impact of AR simulations. On one hand, social concerns should not be ignored during attempts either to handle AR devices or to replace human activities with significant social effects(Azuma, 1997). On the other hand, the purely educational impact of the AR simulations can drastically contribute, among others, to the essential understanding of space, to the design process its shelf and to the architectural educational practice in an altered way of working.

The main scientific impact categorization of architectural indoor AR 3D simulations covers the whole range of Architecture scientific field. The 'changes of proposed structures'categoryisone of the main pillars of Architectural Conception and Approach as it relates to construction, to building refurbishment and to construction materials / equipment. In parallel, the above category, also concern project information and other technical data of the project management system linking to Building Information Modeling (BIM). Finally, this category covers all aspects of post-Completion phase, such as testing, assessment, inspection and review of a building's performance.

The 'design process' categoryconstitutesthe architectural conception process itself. This architectural process is very complex, it includes many phases, it is completely influenced by the respective Engineer Architect or Designer while it takes into account multiple evolving parameters. It is therefore obvious that the complexity of the above architectural process cannot be fully covered and assisted in its entirety by any device. Nevertheless, 3D AR simulations contribute drastically to decision-making and to a holistic spatial perception and therefore decisively to an effective collaboration of the stakeholders.

The design process, under the right conditions, can be transformed into an educational process and contribute drastically to education both in terms of knowledge and in terms of cooperation and preparation. However, this work deals only with aspects of the design process which are mainly related to the parameters of the architectural conception process, while the impact of the educational aspect of 3D AR simulations, is the subject of an upcoming publication.

The ‘Guiding visitors’ experiences’ category covers all spatial guiding experiences mainly in Architecture, in Art and Cultural heritage. The creation of this category is related and influenced both by time and by the approach and nature of 3D simulations.This category is related to the respective architectural or artistic result or proposal per time phase as well as to the proposed architectural space, object or work of artaccompaniedbyaccessible overlaying information.In contrast, the ‘changes of proposed structures’ category does not refer to the architectural space as a proposal but as a process of construction, refurbishment and application of materials.

The ‘simulations of interdisciplinary information’ category covers the rest of interdisciplinary information that are directly or indirectly related to the space.This information concern, among others, all kinds of flows with spatial reference (waters, wind, traffic, etc.), spatial properties (temperature, humidity, acoustics, etc.), spatial transformations of systems (structural, mechanical, and hydraulic, etc.), unexploredaspects in Art results (temperature, radiation, material properties, etc.), industrial design results with interactive overlaying information and finally geographic data in a large spatial scale (GIS data, spatial local planning, etc.).

Perspectives:-

The main perspectives of the scientific impact of indoor Augmented Raneality 3D representations are related mainly to the adaptation and the use of relative AR techniques. Particularly, the main perspectives, inter alia, concern the:

1. Adaptation of the current techniques to a more simple and ergonomic system ready to be used in an autonomous way, as a technical advisor, by any non-expert user,
2. Use of very low-cost AR devices and sensors grid installation,
3. Enrichment of 3D spatial representations with audio output,
4. Further expansion of measurements representations including indoor environmental factors, crucial health factors, etc.,
5. Local public networks creation of AR platforms representing 3D information, such as BIM, building modeling and measurements, building quality evaluation and deliberation, etc.

References:-

1. Abboud, R., (2013), Architecture in an Age of Augmented Reality: Opportunities and Obstacles for Mobile AR in Design, Construction, and Post-Completion, NAWIC International Women’s Day Scholarship Recipient 2013.
2. Aftab, M., Chau, S.C., and Khonji, M., (2018), Enabling Self-aware Smart Buildings by Augmented Reality, arXiv:1708.05174v2 [cs.HC], 2018.
3. Ahonen, T., (2012), Augmented Reality - the 8th Mass Medium, TEDx MongKok, TED event.
4. Aitamurto, T., Boin, J-B., Chen, K. and Cherif, A., (2018), The Impact of Augmented Reality on Art Engagement: Liking, Impression of Learning, and Distraction, In book: Virtual, Augmented and Mixed Reality: Applications in Health, Cultural Heritage, and Industry, pp.153-171.
5. AR[t], (2013), AR[t] magazine, Augmented Reality, Art and Technology, ARlab, Vol 04, Nov. 2013
6. Azuma, R.T. (1997). A survey of Augmented Reality. Presence: Teleoperators and Virtual Environments, Vol. 6,No. 4, pp. 355-385, 1054-7460
7. Billinghurst, M., Kato, H. and Poupyrev, I., (2001), The MagicBook—moving seamlessly between Reality and Virtuality. IEEE Computer Graphics and Applications, 21(3):6-8.
8. Bimber, O., Coriand, F., Kleppe, A., Bruns, E., Zollmann, S. and Langlotz, T., (2006), Superimposing pictorial artwork with projected imagery. In: ACM SIGGRAPH 2006 Courses, p. 10. ACM Press, New York.
9. Chan, C.-S., Hill, L. and Cruz-Neira, C., (1999), Is It Possible to Design in Full Scale? In Proceedings of the 4th conference on Computer-Aided Architectural Design research in Asia. Shanghai, China, pp. 43–52.
10. Chung, D.H.J., Zhiying, S. Z., Karlekar, J., Schneider, M. and Lu, W., (2009), Outdoor Mobile Augmented Reality for past and future on-site architectural visualizations, In proceedings of the 13th International CAAD futures conference, Montreal, Canada, pp. 557–571.
11. Damala, A., Cubaud, P., Bationo, A., Houlier, P. and Marchal, I., (2008), Bridging the gap between the digital and the physical: design and evaluation of a mobile augmented reality guide for the museum visit. In: 3rd ACM International Conference on Digital and Interactive Media in Entertainment and Arts, pp. 120–128. ACM Press, New York.
12.Doil, F.; Schreiber, W.; Alt, T. and Patron, C., (2003), Augmented Reality for manufacturing planning, Proceedings of International Immersive Projection Technologies Workshop, J. Deisinger, A. Kunz (Ed.), pp. 71-76.

13.Donath, D., Beetz, J., Grether, K., Petzold, F. and Seichter, H., (2001), Augmented Reality techniques for design and revitalisation in existing built environments, In proceedings of the 21st Annual Conference of the Association for Computer-Aided Design in Architecture, Buffalo, New York, pp. 322–329.
14. Dorta, T., (2007), Implementing and assessing the hybrid Ideation space: A cognitive artefact for conceptual design, International Journal of Design Sciences and Technology, 14(2):119-134.
15. Dorta, T., Kinayoglu, G. and Hoffmann, M., (2014), Hyve-3D: A new embodied interface for immersive collaborative 3D sketching, SIGGRAPH. ACM.
16. Fatah gen Schieck, A., Penn, A., Mottram, C., Strothmann, A., Ohlenburg, J., Broll, W. and Aish, F. (2004), Interactive Space Generation through Play: Exploring Form Creation and the Role of Simulation on the Design Table. In 22nd eCAADe Conference Proceedings, Copenhagen, Denmark, pp. 148–158.
17. Fuchs, P., Moreau, G. and Guitton, P., (2011), Virtual Reality: Concepts and technologies, London, UK: CRC Press, Taylor & Francis.
18. Hsi, S., (2002), The electronic guidebook: study of user experiences using mobile web content in a museum setting. In: International Workshop on Wireless and Mobile Technologies in Education, Växjö, Sweden, pp. 48–54.
19. Kouzeleas, S., (2008), Processes aspects of modeling, interactive digital visualization and multimedia representation of architectural and urban area, In 11th International Conference on Computer Graphics and Artificial Intelligence (3IA'2008), ISBN: 2-914256-10-8, proc. pp. 205-210, May 30-31, 2008, Athens, Greece.
20. Karnik, A., Mayol-Cuevas, W. and Subramanian, S., (2012), MUSTARD: a multi-user see-through AR display. In: Konstan, J., Chi, E., Hook, K. (eds.) Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 2541–2550. ACM Press, New York.
21. Krakhofer, S. and Kaftan, M., (2015), Augmented Reality design decision support engine for the early building design stage, In proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia, Daegu, South Korea, pp. 231–240.
22. Leue, C., Jung, T. and Dieck, D., (2015), Google Glass augmented reality: generic learning outcomes for art galleries. In: Tussyadiah, I., Inversini, A. (eds.) Information and Communication Technologies in Tourism 2015, pp. 463–476. Springer, New York.
23. Lu, W., Nguyen, L., Chuah, T. and Do, E., (2014), Effects of mobile AR-enabled interactions on retention and transfer for learning in art museum contexts. In: Mixed and Augmented Reality-Media, Art, Social Science, Humanities and Design (ISMAR-MASH'D), IEEE, pp. 3–11.
24. Malkawi, A.M., Srinivasan, R.S., (2004), A new paradigm for Human-Building Interaction: the use of CFD and Augmented Reality, Automation in Construction 2004, Elsevier Editions.
25. Milovanovic, J., Siret, D., and Moreau, G, (2017), Virtual and Augmented Reality in architectural design and education an immersive multimodal platform to support architectural pedagogy, 17th International Conference, CAAD Futures 2017, Turkey.
26. Moloney, J., (2007), Screen based Augmented Reality for architectural design: Two Prototype Systems, In proceedings of the 12th International Conference on Computer-Aided Architectural Design Research in Asia, Nanjing, China, pp. 577–584.
27. Natephraa, W. and Motamedib, A., (2019a), Live data visualization of IoT sensors using Augmented Reality (AR) and BIM, 36th International Symposium on Automation and Robotics in Construction (ISARC 2019).
28. Natephraa, W. and Motamedib, A., (2019b), Bim-Based live sensor data visualization using virtual reality for monitoring indoor conditions, Intelligent & Informed - Proceedings of the 24th CAADRIA Conference – Vol. 2, Victoria University of Wellington, New Zealand, M. Haeusler, M. A. Schnabel, T. Fukuda (eds.), pp. 191-200.
29. O'Brien W.J., Dharmapalan V. (2018) Fiatech: History and Perspectives on Future Research. In: Smith I., Domer B. (eds) Advanced Computing Strategies for Engineering. EG-ICE 2018. Lecture Notes in Computer Science, vol 10863. Springer, Cham.
30. Plasencia, D., Berthaut, F., Karnik, A. and Subramanian, S., (2014), Through the combining glass. In: Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology (UIST 2014), pp. 341–350. ACM Press, New York.
31. Penn, A., Mottram, C., Fatah gen Schieck, A., Wittkämper, M., Stoerring, M., Romell, O., Strothmann, A. and Aish, F., (2004), Augmented Reality Meeting Table: a Novel Multi-User Interface for Architectural Design, Recent Advances in Design & Decision Support Systems in Architecture and Urban Planning, Dordrecht: Kluwer Academic Publishers, pp. 213-231.
32. Pierdicca, R., Frontoni, E., Zingaretti, P., Sturari, M., Clini, P. and Quattrini, R., (2015), Advanced interaction with paintings by augmented reality and high-resolution visualization: a real-case exhibition. In: Paolis, L., Mongelli, A. (eds.) Augmented and Virtual Reality, pp. 38–50, Springer, New York.

33. Raskar, R., Welch, G. and Fuchs, H., (1998), Spatially augmented reality. In First IEEE Workshop on Augmented Reality. San Francisco, California, USA, pp. 11–20.
34. Regenbrecht, H., Baratoff, G., (2005), Augmented Reality Projects in the Automotive and Aerospace Industries, IEEE Computer Graphics and Applications 25(6):48-56.
35. Rhodes, T. and Allen, S., (2014), Through the looking glass: how Google Glass will change the performing arts. Arts Management and Technology Laboratory, Carnegie-Mellon University, pp. 1–12.
36. Sorensen, S., (2006), The development of Augmented Reality as a tool in Architectural and Urban design, Nordic journal of architectural research, 19(4).
37. Soyoung, P. and Choi, J.W., (2004), Retrieving and browsing information of building equipment using Augmented Reality techniques, In proceedings of the 9th international conference on Computer Aided Architectural Design Research in Asia. Seoul, Korea, pp. 911–926.
38. Stojanovic, V., Trapp, M., Hagedorn, B., Klimke, J., Richter, R., and Dollner, J., (2019), Sensor Data Visualization for Indoor Point Clouds, 15th International Conference on Location Based Services (LBS 2019), Vienna, Austria.
39. Sylaiou, S., Economou, M., Karoulis, A. and White, M., (2008), Evaluation of ARCO: a lesson in curatorial competence and intuition with new technology. Comput. Entertainment 6(2):23.
40. Sylaiou, S., Mania, S., Karoulis, A., and White, M., (2010), Exploring the relationship between presence and enjoyment in a virtual museum. Int. J. Hum Comput Stud. 68(5):243–253.
41. Tredinnick, R., Anderson, L., Ries, B., Interrante, V., (2006), A Tablet Based Immersive Architectural Design Tool. In Proceedings of the 25th Annual Conference of the Association for Computer-Aided Design in Architecture, Louisville, Kentucky, USA, pp. 328–340.
42. Vaai, J., Moloney, J. and Moleta, T., (2014), Integrating project management and Mobile Augmented Reality, In proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia, Kyoto, Japan, pp. 951–952.
43. Wang, X., (2007), Using Augmented Reality to Plan Virtual Construction Worksite, International Journal of Advanced Robotic Systems, 4(4).
44. Yoon, S., Elinich, K., Wang, J., Steinmeier, S. and Tucker, S., (2012), Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. Int. J. Comput.-Support. Collaborative Learn. 7(4): 519–541.
45. Yoon, S. and Wang, J., (2014), Making the invisible visible in science museums through augmented reality devices. TechTrends 58(1):49–55.
46. Yusuke, S., Fukuda, T., Yabuki, N., Michikawa, T. and Motamedi, A., (2016), A Marker-less Augmented Reality system using image processing techniques for architecture and urban environment, In proceedings of the 21st International Conference on Computer-Aided Architectural Design Research in Asia. Melbourne, Australia, pp. 713–722.
47. Zhao, S., Zhang, L. and De Angelis, E., (2019), Using augmented reality and mixed reality to interpret design choices of high-performance buildings, 2019 European Conference on Computing in Construction, Crete, Greece, July 10-12, 2019.