The evolution of information flows in construction projects: a contemporary study on the embracing of Augmented Reality

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Abstract: The successful completion of a construction project involves the collaboration of various stakeholders which generates extremely exhaustive and varied information. Consequently, the effectiveness of the information flows ominously impact the strong work relationships between project stakeholders. Even though various adversarial effects to the construction project management threshold; cost, quality and time, are triggered by disordered information trails, numerous barriers for the effective information transfusion stay as a grey area. As an innovative tide towards overpowering the information management barriers in a conventional construction project, execution of Augmented Reality (AR) has been highlighted by scholars. Even though AR is already being incorporated in industries like automobile and aviation, it has not yet been considerably executed in the construction industry. Therefore, to exploit the potential of AR to improve information management, a qualitative research approach was incorporated. The extensive literature synthesis revealed the sustainability to adopt AR in the construction industry while highlighting the associated barriers in its pathway. In conclusion, the AR implementation for mitigating the barriers was evaluated and it indicated on AR's promising nature for such mitigation. This study will be an initiative to integrate the conventional construction environment with AR to enrich the efficiency of project information management.

Keywords: Augmented Reality (AR); information flows; information management; barriers to information management.

1. Introduction

Innovation is much essential to perform existing activities from a different perspective to achieve convenience and greater efficiency in any business (Bygballe & Ingemansson, 2014). However, the innovativeness in the construction industry which is known for highly labour intensive and outmoded mechanisms is not in a sturdy position and subsequently, it has caused the deprived value in return for mega investments compared to the other trades (Zubizarreta, Cuadrado, Iradi, Garc´ıa, & Orbe, 2016).

The success of a construction project can be appraised upon the well-known project management threshold of time, cost and quality (Lambropoulos, 2013). Even though the success of a project is influenced by such factors, communication within the project environment can also be considered as a key aspect to a project management pathway lead towards the productivity (Vasanthi & Abubakar,

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2011). Accordingly, Keyton (2011) defined the communication in a construction project environment as the process of transferring information; ideas, thoughts, orders, views, feelings and emotions through writing, speaking, signals and actions among the project stakeholders. Thus, Donsbach (2006) identified the need for a meeting of minds between the sender and receiver as a result of such information exchange. However, Priyadarshani and Kumar (2015) viewed the complexity in project communication due to the involvement of a larger number of stakeholders and the diversity of information within the construction projects. Accordingly, any construction project output may lead to a catastrophe as in the result of inadequate information management between its participants. Therefore, Rajhans (2013) demanded a proper collaboration and integration of information at every level of a construction project to have strong information channels between the stakeholders.

In response to such burdens, Rankohi and Waugh (2013) identified the importance of innovative information technologies for the Architecture, Engineering and Construction (AEC) industry, due to its complex supply chain nature and high demand for access to information for evaluation, communication and collaboration. Accordingly, many scholars have started to speculate on Augmented Reality (AR) as one of the powerful information management techniques which can significantly benefit the communication through visualization and by exploring real-world structures together with additional contextual information (Kalkofen, Sandor, White, & Schmalstieg, 2011). However, Daponte et al. (2014) found out the adoption of AR in AEC industry to mitigate the communication barriers is in a primitive stage compared to other industries like automobile and aviation with obvious productivity enhancement. Consequently, this paper acknowledges the technological viability to adopt AR into the information management in construction processes while highlighting its effect towards the information channels.

2. Background

The term communication is commonly expressed as the process of transferring information from one person to another (Keyton, 2011). As Donsbach (2006) identified, unless the exchange of information achieves a *consensus ad idem* of the sender and receiver, a productive communication does not occur. Accordingly, the communication process fundamentally comprises of three components; sender, medium and receiver (Oppong & Birikorang, 2014). The further clarification on communication process revealed that the communication will be initiated by the sender through encoding the idea in a form of verbal, nonverbal or written. The message will be decoded by the receiver into meaningful information (Lunenburg, 2010a). However, the communication process can be obstructed by environmental and personal barriers (Oppong & Birikorang, 2014). Further to authors, whatsoever distorts a message can be considered as a barrier in terms of language, interludes, and different perceptions of the message. Finally, the feedback occurs when the receiver responds and returns it to the sender (Lunenburg, 2010). Consequently, the sender can decide whether the message has been received and understood by the receiver.

In light of the above general explanation on communication and its process, Priyadarshani and Kumar (2015) viewed project communication as the process of exchanging of project-specific information among the participants to form a common attitude. Information within construction projects is usually diverse due to the involvement of various parties in many stages (Dainty, Moore, & Murray, 2006). Therefore the success of a project is highly influenced by the information management aspects to have a proper collaboration and integration among the project stakeholders (Valitherm & Rahman, 2014).

2.1. Information flows in a construction project

Information flows in a construction project can be identified under three distinct directions as downward, upward and horizontal (Lunenburg, 2010). Downward flows transmit information from higher to lower levels in the organization structure. In construction projects, this type of flows sends information such as notices, regulations and memos from supervisors to subordinates (Turkalj & Fosic, 2009). As identified by O'Toole, Meier and Crotty (2005), information is transmitted from a lower level to the higher level through the upward information flows. An instance of engineering team sends suggestions, the progress of works, and explanations to the chief engineer can be considered as an example for upward information flows. Moreover, information transmission between the participants who are in the same level of the organization structure is considered as horizontal information flows (Turkalj & Fosic, 2009). Horizontal information flows are more important for the coordination within the construction team. In addition to these three types of basic information flows, 'Lateral communication flows' are there along the different paths in addition to the hierarchy of the organization (Vasanthi & Abubakar, 2011).

Furthermore, Turkalji and Fosic (2009) described the construction information flows under the categorisation of formal and informal. Formal information channels transfer information such as the procedures, goals and policies within the project environment (Kandlousi, Ali, & Abdollahi, 2010). Moreover, the authors found out that formal communication occurs as a systematic process in a pre-planned pathway and follows a chain of command. However, Turkalj and Fosic (2009) claimed of inevitable existence of informal communication networks in any formal working environment to fill any gaps caused through strict and hierarchical communication. On the other hand, the authors identified the need for a proper balance between formal and informal communication to avoid any chain of command being disrupted by informal communication.

3. Research Method

This paper expects to answer the research problem of "how far the AR can be incorporated into the construction processes to eradicate the barriers for effective information management" through a qualitative research method. Thus, the qualitative research method is appraised as its ability to achieve an in-depth analysis of incipient and new concepts which are also consisted of trivial literature supporting. Accordingly, this research is mainly focussed upon an in-depth investigation on literature sources about the implementation of AR in the construction industry concerning mechanisms to incorporate AR in construction project stages, information management through AR's perspective and barriers for such integration.

4. Augmented Reality (AR)

Carmigniani (2011) simply defined AR as "actual view of a built environment that has been enhanced by adding the virtual information" (p.377). An AR system aims to syndicate the real world with the computer-generated world to appear as a uniformed environment (Yuen, Yaoyuneyong, & Johnson, 2011). Therefore AR can be simply described as a type of Virtual Reality (VR) where the display is transparent. Although virtual reality is the approach where the user is completely immersed in a virtual environment, AR allows the user to interact with both the virtual and real objects in a seamless manner (Zhou, Duh, & Billinghurst, 2008). Further, the authors have explicated that when the user is moving around the real objects, the virtual objects are acting as they are completely integrated with the real world. Even though the virtual objects move, their movements will seem as they are registered to the real world, providing the user with a perception of an integrated working environment (Yuen et al., 2011). Accordingly, users can acquire additional information of real-world by rendering this mixed overlay in devices such as head-mounted displays, see-through glasses and hand-held monitors (Jiao, Zhang, Li, Wang, & Yang, 2013).

The core in an AR system can be considered as the software and database running in a portable computer (Sørensen, 2013). The database comprises of the 3D models which are to be viewed and their geo-location. These are positioned by the software consistent with the data retrieved through the registration systems. Then the composite renderings of the virtual model will be superimposed by the software, on the display device based on the data of location, the orientation of the viewer and virtual model, and the field of view of the display device (Sørensen, 2013). The 'Augmented Reality' was coined as a term in the early 1990s by Caudell and Mizell who developed an AR system to assist workers at Boeing Corporation (Agarwal & Thakur, 2014). At present, numerous mobile platforms such as smartphones, tablet PCs and personal digital assistants (PDA) are capable of supporting AR technologies (Agarwal & Thakur, 2014). Moreover, it has become possible because of modern technologies to develop AR applications by simply using software development tools such as ARToolKit which are available free of charge (Li, Yi, Chi, Wang, & Chan, 2018).

5. Barriers to Effective Communication

To achieve effective communication, particular information should be reached to the receiver only with negligible distortion, without altering the core idea noticeably (Cheng et al., 2001). However, complications in ineffective communications occur when the receiver does not fully understand the particular information sent by the sender. In the construction industry, studies have identified various difficulties in sharing information between the stakeholders due to the unique nature in project setups (Zeng, Lou, & Tam, 2006). Accordingly, such barriers may create disturbances and interferences result in ineffective communication. As identified by Priyadharshini and Kumar (2015), the impacts resulted by inefficient communication in construction projects are the delays in projects, overrun of cost due to rework, lack of coordination, lack of quality of works, reduced performance of the organization, delays in procurement, misunderstanding and misrepresentation, changes in scope, failure of the project, risk initiation during closeout phase, disputes and arbitration.

Various researchers have classified the barriers to communication in construction projects under several methods. Lunenburg (2010a) has divided the barriers for effective communication into four categories as a process, physical, semantic and psychosocial. Process barriers comprise of the barriers invoice with the components in the communication process such as; sender barrier, encoding barrier, medium barrier, decoding barrier, receiver barrier, and the feedback barrier (Lunenburg, 2010a). The physical attributes of the environment which negatively affect the effectiveness of the communication can be considered as physical barriers (Nijkamp, Rietveld, & Salomon, 1990). Examples of physical barriers are environment or climate, time and distance, and technical problems. Semantic/ language barriers can be considered as the most common communication barriers which result in misunderstandings or misinterpretations (O'Leary, Federico, & Hampers, 2003). Lunenburg (2010a) has identified the psychosocial barriers in three types as experience, filtering, and psychological distance. Examples for causes of psychosocial barriers are memory, selective perception, filtering and attention, culture, and tradition.

Dainty et al. (2006), Priyadharshini and Kumar (2015), Luka et al. (2014), and Valitherm (2014) acknowledged a common set of barriers for efficient communication in construction projects. Accordingly, the complex nature of information transmitted within a construction project environment has been identified as a barrier to achieve the efficiency where information is diversified and specialised upon the transmitter's professional expertise. Therefore, the receiver might not have the required knowledge or proper understanding to decode the message which would ultimately create a disturbance or misunderstanding in the flow of bureaucracy. In line with this particular hindrance, Dainty, Green and Bagilhole (2007) viewed the complexity of information as in the result of heavy workforce diversification in a construction project environment. It is a well-known fact that the construction workforce consists of a wide range of occupational cultures such as skilled, unskilled, managerial, professional and administrative which requires a proper stakeholder management mechanism to achieve a common communication ground in between these professional layers. Further, studies have identified that language and cultural discrepancy among the construction workforce would also complicate the effective information flows within the construction project environment. Because professionals and workforce from different countries and races would be employed in construction projects which roots for a community with different languages and cultural norms. Rather than those, above studies emphasised on lack of clear objectives, faulty transmission through inappropriate mediums, and less use of innovative information technologies as to cause barriers to achieving effective information flows among the construction project stakeholders.

6. Application of AR for Information Management in the Construction Industry

Currently, AR technology in construction industry intends to improve the practices of design process, architecture visualization, engineering management systems and building construction processes (Wang, 2009). Dunston and Wang et al. (2014) found out that the information accessibility for decision making on work planning, design reviews, work execution and monitoring can be enhanced through a combination of real and virtual environments. Rankohi and Waugh (2013) have further identified numerous capabilities of AR in AEC industry such as; virtual site visits, pre-empting schedule disputes, comparing as-built and as-designed works, enhancing collaboration, training/ planning for similar projects.

As said by Dong and Kamat (2013), the AEC industry can be benefited by AR at least in three levels of visualization, information retrieval and interaction. Accordingly, Dunston and Wang (2007) have explored potential applications of AR for training operators in heavy construction equipment. A 4- dimensional AR model has been developed by Golparvar-Fard, Peña-Mora and Savarese (2009) for automating activities in construction phases such as data collection, progress monitoring, processing and communication. Further, Behzadan and Kamat (2011) have investigated a mobile 3-dimensional AR system to visualize the dynamic site operations in the construction stage. To record the construction progress, a web-based augmented panoramic environment has been developed by Wang, Cho and Gai (2012). Therefore, it is evident that the construction industry is now moving towards AR technologies to achieve added benefits in information management of a construction project (Rankohi & Waugh, 2013). Accordingly, the application of AR for information management in a construction project will be discussed in this paper under the design and construction stages.

6.1. AR in the design stage of a construction project

Architecture and design industries require in-built visualization platforms for the efficient use of digital information (Dunston & Wang, 2005). Further, the authors have acknowledged AR to provide a unique advantage of integrating the design into the as-built environment perspective. Accordingly, a building scheduled on a future date can be showcased through AR by letting the customers realize on how the building will look in real and also pre-visualize its placement (IndexARSolutions, 2018). An AR system for the architectural design visualization has been firstly developed by Kensek, Noble, Schiler and Tripathi (2000) for indoor facility management and maintenance. AR systems can be used also for on-site experiences by the project stakeholders such as architects, designs, constructors, owners to observe the appearance of a new design and to evaluate its functions and aesthetics (Sørensen, 2013). Thereby, AR can assist the project stakeholders to safeguard the quality assurance and constructability review.
During the design stage of a project, a large amount of data and information would be utilised by various project stakeholders and a potential application of AR would allow them to access such information cooperatively through an augmented workspace (Wang, 2009). As stated by Wang et al. (2014), usually the placement of a building is demonstrated by the designers through creating scaled physical mock-ups or digitally enhanced photographs which are expensive and time-consuming processes. Hence these difficulties can be mitigated with AR prototypes and test platforms (Wang et al., 2014). Moreover, AR "popup" models is another approach that links AR models with physical drawings while allowing the users to understand them comprehensively (Dunston & Wang, 2005). Further, Wang (2009) has mentioned that most of AR applications for architecture and design have incorporated the "ARToolkit", a platform to simplify the possible implementation of AR in construction projects.

6.2. AR in the construction stage of a construction project

Different stakeholders involved during the construction stage of a project, mainly provide attention to their tasks with less focusing on interdependencies among the tasks. Whereas AR provides an integrated sight of the components for project participants at the right location in real scale and time (Wang et al., 2014). As identified by Dunston and Wang (2005), AR enables project partners to work collaboratively by moving the map in a seamless way of having an immersive view of the design. Each of the project participants can communicate on complex relationships between several constructions works in a more comprehensible manner rather than using computer-generated sketches (Wang et al., 2013). As further explained by Wang et al. (2014), wastage of money and time due to misinterpretation of drawings can be reduced with the use of AR by having a better link between information and physical resources.

Further to Jiao et al. (2013), AR can be applied in the construction stage of a project in various areas such as progress monitoring, conflicts avoidance, cost control and tenant management. As one of best uses of AR, construction works can be inspected by examining the alignments of as-built conditions compared with as-designed drawings of models to discover discrepancies (IndexARSolutions, 2018; Rankohi & Waugh, 2013). Further Wang et al. (2014) have stated that the progress of the construction works can be determined by overlaying as-planned models on the as-built situations. For example, various colour schemes can be used to indicate the building components as "behind schedule", "on schedule" and "ahead of schedule" (Wang et al., 2014). Moreover, information retrieval can be enhanced through the use of AR with several mechanisms to filter data and information and removing redundant data to get the most relevant information (Chu, Matthews, & Love, 2018).

Use of AR will accelerate the construction tasks since it depresses the frequency of switching between the workpieces of tasks and related information resources by making the information readily available in a real context and real-time (Wang et al., 2014). Therefore, AR can provide instructions for the workers such as correct work procedures by displaying digitalized information to improve accuracy and safety (Li, Yi, Chi, Wang, & Chan, 2018). For example, when a technician is performing a task while looking at the information on papers, it is inevitable to avoid the physical and mental detachment from the designated work repeatedly. However, if the technician has worn a head-mounted display with an AR system to instruct, AR system will retrieve information to perform the work seamlessly (Wang et al., 2014). Further, the AR can be used to determine the exact positions to place the components instead of setting out (Dunston & Wang, 2005). Besides, positions of enclosed components can also be figured out effortlessly. For example, an operator of a backhoe excavator can recognize the positions of buried utilities through incorporating AR (Dunston & Wang, 2005).

Also, Wang et al. (2014) have admitted the integration of Building Information Modelling (BIM) with AR to mitigate the lack of information combination between the computer-generated and real world. The authors have revealed that BIM + AR will allow to navigate and find the linked drawings by clicking on a location. Chu et al. (2018) have stated that such integration of BIM with AR can provide an interactive 3D solid model with a visual understanding of details for the workers which may ultimately enhance the constructability.

6.3. Barriers to the implementation of AR in the construction industry

The barriers of implementing AR in a typical industry can be discussed under technical and social barriers (Vakoms, 2017). In this paper, the identified two deviations of barriers will be discussed concerning the construction industry.

6.3.1. Technical barriers

- Miniaturization Issues - To be highly adaptable, the hardware used for AR systems should be lightweight and quick enough to demonstrate graphics (Mekni & Lemieux, 2014). Whereas when it comes to construction, due to the huge amount of information which has to be dealt, high-capacity storage and high-performance components are required (Busel, 2017). Therefore making light and small devices with high performances to the required extent is a challenge.
- Battery life -Portable AR devices are necessary for most of the applications in construction. Hence an adequate capacity of the battery will be required to work uninterruptedly (Mekni & Lemieux, 2014).
- Accuracy and reliability -Enhanced tracking systems are required to display the information is accurate and reliable manner. And the devices should have well-functioning software to obtain, filter and retain the information, discard the inadequate data and display the precise information (Mekni & Lemieux, 2014; Smith et al., 2016).

6.3.2. Social barriers

- Social Rejection - Stakeholders in construction usually tend to embrace common practices which are in their “comfort zone” rather than evaluating and adopting new technological solutions like AR (Mekni & Lemieux, 2014; Busel, 2017). This may raise as a serious issue to uptake AR tools into the existing cultural and social settings of the industry.
- Cost - Cost is generally a key consideration for any technological implementation. Consequently, AR solutions may require an expensive start-up cost for widespread use (Smith et al., 2016).

- Poor Experience - As AR is a novel concept in much orthodox construction industry, it is obvious that the professionals may not have the required knowledge or experience in working with AR. Thus, professionals are required to be trained or hired (Mekni & Lemieux, 2014; Busel, 2017).
- Health and safety issues -Digital fatigue may occur as a result of excessive use of digital displays. For example, health problems such as eyestrain and migraines may happen. Further, when a person uses AR displays on the site, his surroundings will be covered by the augmented contents and it may cause for physical danger. (Smith et al., 2016; Busel, 2017).

As per the overall findings, it can be identified that the use of AR will be positively effective for mitigating each barrier to communication in construction. Accordingly, the applicability of AR for mitigating the communication barriers can be condensed to a comparable manner as depicted in Table 1.

Table 1: Potential of AR to mitigate the barriers to communication.

Barriers to communication in a construction project	**Potential of AR to mitigate the identified barriers**
Convolution of data	* Associated real-time encounter with a 360-degree visualization • Intersecting additional data such as dimensions, features, assignment span • Facility to inspect outlined 3D illustrations on definite locations in a live setting
Diversified workforce	* Capability for any skill levels of persons to learn on-site graphical data • Ability to supervise aides with optical directions • Observing the operations and recognising flaws
Communication struggles	* Enhanced understandability of expressed messages with concurrent application of AR visualization • Translating features of the overlaid information
Absence of precise purposes	* Presenting a precise opinion on possible conditions on site • Comprehensibility for the persons who are unknown with the circumstances
Inadequate conveyance	* Presenting a fitting insight into the information for discovering suitable transmission techniques
Insufficient capital	* Reducing the expenses for samples via visualizing with AR • Decreasing the accidental project expenses
The restricted practice of innovative information management tools	*The expectation to be welcomed by the people due to the elite experience given by AR

7. Conclusions

The comprehensive literature synthesis provided knowledge on the components, mediums and the patterns of the communication and the importance of effective communication for construction projects. It was identified that proper communication is essential for the successfulness of project delivery. Whereas findings indicated that barriers to communication in construction remain. As per the findings, implementing AR in construction is viable based on the current technological means. However, the accuracy and reliability of the functioning of AR will depend on the scale. Therefore, AR can be initiated with a capable level and gradually, the AR applications can be expanded with the development of the technology. Moreover, this study acknowledged the barriers to implement AR in the construction industry. Among those, most of the social barriers occur due to the unawareness of people about the applicability of AR technology and its conceivable benefits. Therefore, making construction professionals knowledgeable about every aspect of AR is foremost to overcome most of the social challenges. Considering the overall findings, it can be concluded that applying AR in construction will be positively affected to mitigate the communication barriers and in enhancing the efficacy of information management in construction projects.

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