Spatial Cognition: A Sign of Successful Communication Representation between Professionals on the AEC's Design Process

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Abstract. The increase in the complexity of the AEC projects has made the design process more complicated due to the earlier need to embrace different professional requirements. Collaborative work is recommended where multiple individuals come together to resolve complex design problems. Hence, seamless communication between different disciplines, teams, and sub-teams during the collaboration ensures the eventual delivery of the projects. This study is the first part of a more comprehensive empirical effort to explain the effectiveness of communication on collaboration between design professionals during the design process. The study conducted a selected literature review to understand and document the best approaches in enhancing the communication, which would allow adequate spatial cognition, thus facilitating the participatory collaboration between multiple disciplines during the design stage. The results revealed that *spatial cognition* is a critical aspect of design collaboration in the AEC projects to improve professional-to-professional communications. The results are expected to contribute to determining a precise design process flow which could prevent potential conflicts and reworks during the later construction phase. In turn, integrated project delivery of complex IBS projects could be made easier, which thus would reduce material and financial wastages for the project owners.

Keywords: Design Collaboration, Communication, Spatial Cognition, AEC Professionals, Integrated Project Delivery, Design Informatics.

1 Introduction

It is well agreed that numerous lengthy processes are followed when it comes to a building project. These processes encompass project conception, realization, handover, and operation. As such, the processes typically embrace several individuals and organizations to deliver. This lengthy process starts with the design that is known as the fundamental for success of the projects. To support the design's impression in Architecture, Engineering and Construction (AEC) projects, Chua et al. (2003) declared that a momentous role is played by the design in the cost-effectiveness, timeliness, and quality of the entire AEC projects. Therefore, there is a need to narrow down the design process to have a deeper understanding and find the challenging parts of this critical stage that could be known as a stepping stone for further promotion of the AEC projects' lifecycle.

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1.1 Design Process

Drawing a comprehensive definition for the design seems somehow complicated due to the nature of the design as a contextual phenomenon. For example, Sebastian and Prins (2009) highlight that the design is commonly considered as a black box containing processes involved in finding a problem and solving that problem. Simon (1982, 1996) basically defined the design having three characteristics as (1) a process (2) which is goal-oriented, (3) whose goals are resolving the problems, fulfilling the desires, improving the conditions, or generating something novel or praiseworthy. In support of Simon's endeavors, Friedman (2005) described the design as an activity utilized by designers to solve problems, create something new, or transform fewer desirable situations into preferred situations.

Besides, Lawson (2006) stated that the design constitutes from steps that are taken in different respects: analysis, synthesis, and evaluation. Stempfle and Badke-Schaub (2002) pinpointed that the design process is generally considered as a sophisticated phase that escalates concerning the design's nature, where the designing is considered as a specific area of problem-solving. Atsrim et al. (2015) also maintained that the design is a multifaceted act which embraces numerous resolutions. These vary from conception to selection of a solution in face of several other thinkable choices. Therefore, any likely failure of the design could contribute to numerous consequences for the projects. As evidence, Undurraga (1996) suggests that design insufficiencies are responsible for roughly 20-25% of the total loss of the construction time. Likewise, Koskela (1992) acknowledged that about 78% of the AEC quality problems of the projects are attributable to the design. On the other hand, Ensici et al. (2013) stated that due to increasing market demands and rapid technological developments, the AEC projects are being expanded in various aspects such as size, functions, and complexity. A collection of all these stated aspects renders the design process as a complex stage of the lifecycle of the AEC projects so that the design and its problems are becoming much more complicated.

Therefore, concerning the motion of the projects towards complexity, the design needs to be carefully conducted and managed. However, as a project becomes much more complex, new aspects of the delivery of the projects open up. Some of these aspects include the participation of professionals during the design process of complex projects. Hence, a recent phenomenon in design that seems necessary in conducting the design process is the involvement of teams, sub-teams, and individuals with different expertise from various disciplines, who are called AEC professionals.

1.2 AEC Professionals

Currently, most construction projects are becoming complex due to numerous reasons such as sizes, types, developments, and functionalities. As the projects become complex, the design process gets complicated and accordingly, there is a dire need for numerous teams, sub-teams, and individuals to deliver the projects. This is supported by Chiu (2002) claiming that many of the most critical decisions are made in the design stage because of conducting activities. These activities encompass briefing the client, collecting the data, formulating the architectural program as well as generating the schematic design. Likewise, Chiu et al. have emphasized the need for the AEC professionals to deliver the design process. In practice, it is asserted that these conducting activities have the potential to push the projects towards the complexity of the tasks,

leading the design process to become a complicated stage that needs to be delivered by the AEC professionals.

Indeed, Stempfle and Badke-Schaub (2002) proposed that increasing complexity leads various groups of individuals to work together in order to solve the design problems. To support these statements, Ensici et al. (2013) recommended that delivering the design in complex projects needs several specialists rather than one single designer to accomplish all the duties required by a design stage. Likewise, Sebastian and Prins (2009) claimed that once a given project gets more complex, there will be a dire need for recruiting more specialists. This is so because their endeavors could be combined with substantial eagerness and commitment in order to collaborate with each other and ultimately fulfill the objectives defined for the given project. For the meantime, it is acknowledged that notwithstanding the striking capabilities of an individual designer, the scope of knowledge necessary for perceiving the entire angles of a certain complex problem is claimed to be beyond the cognitive boundaries of a single individual (Arias et al., 2000; Vande Moere et al., 2008).

However, each group or individual who participates in the design process of the AEC projects has certain plans, goals, and aspirations, which may not be congruent with the project goals, which per se causes the tasks to become more complicated (Walker, 2002). For that reason, Sebastian and Prins (2009) underscore that collaboration in the design, which includes the participation of numerous professionals, has become an absolute necessity to respond to the requirements of complex projects, like the IBS projects. Eventually, it could be added that as several researchers highlighted involving different members of design professionals to participate, communicate, and collaborate, these requirements could be known as a stepping stone for using the collaboration concept to deliver complex AEC projects (Arias et al., 2000; Vande Moere et al., 2008).

1.3 Collaboration

In general, Moum (2006) declared that globalization and increasing technologies and products require more teamwork to succeed, which causes the projects to get complex. To respond to the complexity of the projects, Kleinsmann (2006) stressed that collaboration is an essential factor for the success of complex projects. Besides, Singh, Gu, and Wang (2011) highlighted that due to the exchanging of extensive building datasets in most of the AEC industries' complex projects, there is a need to involve multi-disciplinary collaboration. Moreover, it is admitted that efficient collaboration exerts certain impacts on the quality of the designed products since the design process in current projects is collaboratively delivered thanks to numerous professionals from different disciplines (Valkenburg & Dorst, 1998). Therefore, collaboration could be counted as one of the pioneering concepts to apply for responding to the complexity of the design process of the projects.

Gül (2009) defined collaboration in design or collaborative design as an activity that entails numerous specialists who team up to fulfill a shared goal. Similarly, Kleinsmann (2006) underscored that collaborative design implies a procedure whereby specialists coming from diverse fields exchange their know-how concerning the design processes and contents with the ultimate aim of reaching a communal perception. This finally enables them to assimilate and probe each other's knowledge and to fulfill a grander shared goal i.e. designing a new product.

Indeed, collaboration in multi-disciplinary teams is presented with the intention of yielding more comprehensive perspectives concerning a given problem prior to making any project resolutions (Olson et al., 1992; Geisler & Rogers, 2000). In this way, the actors in fact, team up so that they will have adequate information required for elaborating on the complexity of problems faced by the individuals in the community in the modern era. This can be undertaken merely through assimilating their valuable past know-hows and technical information (Smulders et al., 2008; Feast, 2012).

Based on Kleinsmann (2006), the collaborative design comprises three constituents as follows: (1) creating and combining the knowledge between participants coming from diverse fields (2) communication among them on the design content and process, and finally (3) reaching a common perception on both the content and the process.

Therefore, it is stated that actors within the design of a collaboratively conducted project attempt to address mutual goals to complete the projects through communication between the members. Subsequently, the communication here renders its effects on the collaboration quality, which is why there is a need to consider communication as one of the essential factors of collaboration in the design stage that could influence the process and content of the design.

2 Research Methodology

This study involves a literature survey on selected topics under spatial cognition: a sign of successful communication representation between professionals on AEC's design process. By making use of Ibrahim's (2008 & 2011) categorization technique on determining the research questions construct, keywords to categorize three Research Question Constructs (RQS) namely "WHO," "WHAT" and "HOW" were determined. According to Ibrahim (2008 & 2011), "WHO" refers to the element being employed or influenced by research whereas "WHAT" implies the information needed for solving a research problem, and finally "HOW" denotes any action or effect on the research element or information (Ibrahim, 2020). This study covers the design process, communication representation, and AEC professionals under "what is a significant factor for successful communication representation between professionals in AEC's design process?"

This exercise outcome would contribute to the production of a synthesized summary for a certain topic. This paper has considered the cross-analysis and did an integration on the possibilities while prioritizing the synthesized information, which ultimately geared in the direction of highly feasible solutions in a collaborative process to enhance the quality of the design process of the AEC projects and prevent the likely failure during the design process in a flowchart (see Figure 1) (Ibrahim & Rafeah Mustafa Kamal, 2018). This paper culminates with a discussion on possible integrated solutions useful for developing a proposition in the future to understand significant factors for successful communication representation between the AEC professionals in the AEC's design process.

2.1 Communication between AEC Professionals

Communication is a natural part of a collaborative environment between the design participants (Kim, 2006). Later, Gül (2009) underlined that collaborative design necessitates competent and well-organized communication aimed at developing a communal perception on diverse aspects, including the design problem and concepts, in addition to managing and checking the activities undertaken by each participant plus active involvement of each partaker. According to Feast (2012), communication plays a pivotal role in collaboration. Also, Austin et al. (2001) detailed that communication dominates the quality of the design process. Similarly, Cheng (2003) clarified that collaboration tools are meant to ease teamwork. This is indeed achieved by means of upholding the communication, combining the project information, in addition to enabling accessibility.

Besides, there are many published research studies regarding the significant effectiveness of communication on AEC projects. Some of these pieces of evidence to prove communication effectiveness has been reported by Kähkönen and Rannisto (2015), suggesting that in construction, both communication and data handling make up a proportion of roughly 75% to 90% of the time consumed by the project manager. Likewise, Moum (2006) pointed out that, if it remained unrecognized and unsolved, failing in communication could cause conflicts and misinterpretations, which in turn leads to adverse impacts on the project.

Furthermore, Kleinsmann et al. (2007) pinpointed that design communication is about the process and content, while Anumba et al. (2007) expressed that achieving successful project collaboration is possible by thoroughly and accurately communicating the information from diverse sources in a timely fashion. Hence, it is clear that communication is one of the most critical factors of collaboration in the AEC projects while exchanging and sharing of information in this process is stressed as the most significant material during the communication process. Indeed, communication in general and exchanging and sharing information, in particular, would influence the quality of the design, especially in the context of complex AEC projects.

On the other hand, it is pointed out by Leenders et al. (2003) that design is a creative process, and creativity requires an optimum level of communication so that any limitation in the communication reduces the creativity (Tavčar et al., 2005). Also, Schön (1992) pinpoints that reflections generated via computer-aided design tools can either promote or hamper the designers' creativity in the course of design reasoning. Therefore, this study states that cognitive tools or an external representation used as a means of communication tools for spatial cognition could affect the design creativity by either triggering it or hampering it.

2.1.1. Exchange and Sharing of Information

Zakaria et al. (2013) proclaim that since the information is perhaps the essential construction material, having wrong information, not having satisfactory accessibility, and right information in the project lifecycle could hinder the productivity of the projects. Such a statement is supported by Awomolo et al. (2017), establishing that effective communication through sharing and exchanging information during the design process between the design team members improves team efficiency and allows teamwork to be reaped.

Communication refers to both the exchange and share of information among both the sender and receiver with the aim of equating the information for both parties (Otter & Prins, 2002). In practice, the above-mentioned delineation is in line with sharing meaning undertaken to attain

a communal perception (Otter & Emmitt, 2008) and a cognitive and social process whereby the communications are conveyed, and meaning is spawned (Maier et al., 2008). Likewise, Otter and Emmitt (2007) overstated that in the context of avoiding any misunderstandings and design failures, communication means to exchange the design information by the entire participants and that such information could be geometrical or non-geometrical. Awomolo et al. (2017) defined communication as human behavior that facilitates meaning sharing through the unidirectional or bi-directional transmission while exchange of information is a fundamental component of the design process (Lane, 2000).

By considering all the mentioned definitions and concepts of communication regarding the communication and importance of sharing and exchanging of information between the team members during the design process, it can be concluded that communication works in a way to help the participants to reach a mutual understanding by sharing and exchanging of information. This could be achieved by providing a comprehensive spatial cognition for the participants to reach a mutual agreement.

Briefly speaking, it is proposed by Schön (1992) that as long as action and reflection are implemented, every level of representation will enable the designers to attain a progression in terms of their understandings and notions related to the design solutions. In practice, the design media in this type of cognitive approach are taken into account as any media away from such unpretentious and down-to-earth presentation tools. As such, designers put their faith in external design representations in order to communicate design ideas both to themselves and to others (Gül & Maher, 2009).

Designers are involved in the spatial cognition process wherein the representations are considered as cognitive aids both for memory and information processing. This is achieved through creating external or internal representations (Tversky, 2005). Also, Kim (2006) said that perceptual and functional actions are directly related to designers' spatial cognition. Indeed, for design thinking, because of the fact that interacting with an external representation would enable externalizing a mental representation for reflection and extension, external representations or cognitive tools could act as visual aids in diverse possible ways (Gül & Maher, 2009). Thus, it can be stated that any type of external representation used as a means of communication could be considered as a tool for cognitive aids for the spatial cognition process.

3 Discussion

This study has gotten to a place where reaching a mutual understanding in a collaborative environment could be much faster through comprehensive communication, which would be achieved by providing adequate spatial cognition for the participants during the design process. Besides, the spatial cognition in a comprehensive communication could be counted as one of the catalyzers for providing an improved perception concerning the requirement details, forms, as well as relations between design objects and the elements to the professionals participating during the design process of the AEC projects. Thus, this section attempts to present a deeper understanding of spatial cognition, which could be a backbone for further expanding the design process in the AEC projects.

3.1 Spatial Cognition

Generally, we are all involved in space, and subsequently, in spatial cognition (Tversky, 2005). Tversky and Lee (1998) categorize four spaces in our lives, serving different functions. These spaces include the space of the body, the one around the body, the one for navigation, and the one for external representations. It is admitted that every natural situation is experienced in a different way, which is why it is conceptualized otherwise. However, the interaction with the four spaces is apparently seamless. Because of the prevalence of spaces, 'spatial,' or 'visuospatial,' cognition can be a wide-ranging ground of query which arises from diverse fields, but the common goal of the spatial cognition research is to understand spatial representations and processes, whether real or abstract (Foreman & Gillett, 1997; Knauff et al., 2002). Likewise, Tommasi and Laeng (2012) proclaim that spatial cognition implies numerous mental representations and processes which grow among individuals, including the designers, to help them handle the physical dimension in the space. Therefore, this study will further elaborate on spatial cognition by defining spatial cognition, stating its significance, and how to enhance it between the AEC professionals participating during the design process of the complex projects. To define the spatial cognition, Kim (2006) briefly reviewed several theoretical perspectives on designing to give a specific context to the definition of 'spatial cognition in designing', which is also accepted by the authors of the current study. However, inconsistencies exist in relation to the so-called spatial cognition owing to the multiplicity of the methods and the associated disciplines (Foreman & Gillett, 1997). Thus, this study defines the designer's spatial cognition based on cognitive design studies and research into spatial cognition.

Beisdes, there are multiple external representations beneficial for designing in providing external tokens for design ideas that must otherwise be kept in mind, reducing designers' working memory. These mediums serve as a visuospatial cue, evoking related functional issues that might not otherwise be retrieved (Suwa & Tversky, 2002; Kim, 2006). Therefore, spatial cognition can be defined as visuospatial reasoning through visual perception and the construction of mental representations. Even though it is stated that the visuospatial representations are meant for capturing the object's static and dynamic aspects, visuospatial reasoning is meant to be a foundation for abstract inference, which in turn moves aways from only visual information retrieval (Bruner 1973). In terms of designing, visuospatial reasoning occurs on external representations such as textual, graphical, and 3D scale models that extend designers' limited cognitive abilities by serving as memory aids and a means of communicating, computational offloading and reasoning (studies cited in Kim and Maher, 2008). Therefore, it can be said that external representation could have the ability to enhance the spatial cognition of the design professionals through providing various types of information, whether geometrical or non-geometrical.

According to Vega et al. (1996), there are two diverse manners whereby individuals process visuospatial information. The first manner of attaining information is via visual perception in relation to the visual properties of any object, elements, constituents, particulars, and spatial relations existing between those objects plus the existing motions. It is of note that visual perception systems handle the shift from sensation to perception. In such a system, the perceptual images of spatial scenes will be created through a bottom-up approach regarding the edges, surfaces, and shadows. Nonetheless, besides visual perception, individuals deal with the visuospatial information deprived of any sensory support resulting from a top-down retrieval. At times, creating the virtual images is undertaken in lieu of either explicit or implicit task

demands. It is reckoned that individuals can mentally integrate visuospatial elements more differently while executing and simulating mental transformations on them and getting involved in both reasoning and problem-solving. All these are possible via constructing mental representations.

Therefore, this study assumes that these two significant aspects of people's information processing could be achieved by providing adequate and comprehensive spatial cognition during the design process for the AEC professionals.

In line with this, Kim and Maher (2008) stated that reflective collaboration among the external representation and the designer's internal cognitive model is called the designers' spatial cognition, which is handled via perceiving and reasoning on visuospatial information (Goldschmidt and Porter, 2004; Visser, 2004). The former, i.e. perceiving, refers to reception and understanding the information from the representations while the latter, i.e. reasoning, implies the procedure to think and solve the problem that surpasses the provided information and that is connected with the artifacts and space.

For example, Kim and Maher's (2008) results revealed that the use of Tangible User Interfaces as an external representation altered the designers' spatial cognition while such alterations influenced the design process by increasing the designers' problem-finding behaviors. In practice, it is confirmed that such a change ultimately resulted in the creative design. Thus, by considering these statements, the current study assumes that the spatial cognition existing among the design participants during the design process could be affected by communication tools or external representation, leading to creativity in the design.

Moreover, Kim (2006) specified that designers perceive visuospatial features from the external representation with or without sensory support. Such perceived information acts as a sign to reason in relation to the functional issues throughout the design process. In addition, despite the fact that space is multi-modal, spatial reasoning can be facilitated by visual information that serves as cognitive tools. Consequently, to support designers' spatial cognition throughout the design process, their numerous senses have to be used in order to support their spatial cognition (Tversky, 2005; Kim, 2006).

Eventually, by taking into consideration the synthesis of the given statement, this study proposes to use the Building Information Modelling (henceforth BIM) as an external representation or a cognitive tool for the AEC design professionals participating in the design process of projects, especially complex ones like the IBS. Besides, the proposition of this study supports the statement of Suwa and Tversky (2002), claiming that external representations are indeed visual aids used to solve problems and think creatively. Then, the BIM can enhance the internal cognition of the user as an external representation according to its numerous documented contributions.

Ultimately, in complex AEC projects, like the IBS that has a specific design process method (Delfani et al., 2016), the BIM and its tools can enhance the spatial cognition for the AEC professions participating during the design process of these projects. Indeed, it could be achieved by providing geometrical and non-geometrical information of the objects, forms, components, elements, spaces, and spatial relations that would attempt to facilitate

communication between these participants in a collaborative environment, especially in the design process the complex projects like the IBS ones.

4 Conclusion

Increasingly, it is documented that the projects are becoming more complex, which means they need to be delivered by various teams, sub-teams, and professionals from different disciplines. This phenomenon leads to using the collaboration concept during the design process of complex projects. To have an effective collaboration, there is a need to have seamless communication between professionals and professionals. Hence, comprehensive communication emphasizes the necessity of an adequate spatial cognition that can provide geometrical and non-geometrical information for the participants to reach a mutual understanding in a collaborative environment during the design process.

The current study also proposes that spatial cognition could contribute to determining a precise design process flow which could prevent potential conflicts and reworks during the later construction phase. Additionally, in an integrated project, the delivery of complex projects like the IBS could be made easier, reducing the material and financial wastages imposed on the project owners. Therefore, according to numerous potential contributions on facilitating the design process, it is proposed that the ICT/IT tools like the BIM will have the fruitful potential in achieving the goals aimed by the stakeholders and investors of the complex AEC projects, like the IBS.

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