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IMPACT OF BIM ON BUILDING DESIGN QUALITY

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Building Information Modeling, Information Sharing Capability, Collaborative Decision Capability, Building Quality.

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Abstract

During last decades, the aim of new technologies was to develop new information systems to automate manual processes. Large-scale projects in the field of construction industry need a different approach to organize and analyze data creating a database without any duplication or redundancy. Building Information Modeling (BIM) is a teamwork process using advanced technologies to generate data modeling. Based on a literature review, the present research proposes a set of hypotheses that links BIM implementation with the enhancement of information sharing capability (ISC) and collaborative decision capability (CDC) in the construction sector of the building industry. Consequently, it relates the degree of BIM use to the design quality enhancement using ISC and CDC as mediators. Towards this end, the research adopts three sets of criteria namely, functionality, form and aesthetic values, and building construction quality as indicators to design quality improvement. Finally, the research proposes a new conceptual model to set the potential relations between the different variables included in the study. Hence it offers several implications for practitioners and decision makers concerning the importance of BIM to enhance the design quality.

Keywords

Building Information Modeling, Information Sharing Capability, Collaborative Decision Capability, Building Quality.

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ABSTRACT: During last decades, the aim of new technologies was to develop new information systems to automate manual processes. Large-scale projects in the field of construction industry need a different approach to organize and analyze data creating a database without any duplication or redundancy. Building Information Modeling (BIM) is a teamwork process using advanced technologies to generate data modeling. Based on a literature review, the present research proposes a set of hypotheses that links BIM implementation with the enhancement of information sharing capability (ISC) and collaborative decision capability (CDC) in the construction sector of the building industry. Consequently, it relates the degree of BIM use to the design quality enhancement using ISC and CDC as mediators. Towards this end, the research adopts three sets of criteria namely, functionality, form and aesthetic values, and building construction quality as indicators to design quality improvement. Finally, the research proposes a new conceptual model to set the potential relations between the different variables included in the study. Hence it offers several implications for practitioners and decision makers concerning the importance of BIM to enhance the design quality.

KEYWORDS: Building Information Modeling, Information Sharing Capability, Collaborative Decision Capability, Building Quality.

1. INTRODUCTION

Due to the speed of technological developments in the construction sector, Building Information Modeling (BIM) appears as an organized process that improves communication quality since all BIM-enabled projects are executed in an integrating environment based on information sharing capability (ISC) and collaborative decision capability (CDC). The processes of data communication, interpretation of design information from drawings and documents are complex and time-consuming (Sebastian 2011). The research explores if BIM implementation can facilitate these processes and to whether the use of BIM enhance or control the building quality.

The aim of this study is to propose a conceptual framework highlighting the importance of BIM for the improvement of the design quality. The proposed framework should be based on a sound theoretical background. The research methodology therefore is based on an extended literature review and analysis covering the impact of BIM implementation on building design quality in order to hypothesize on the relations between the BIM Implementation and the building design quality. The outcomes of the literature review set the core concepts to develop a conceptual model that links BIM enabled information sharing (ISC) and collaborative decisions capabilities (CDC) to the building design quality. This model consists of relating these gains to the architecture quality improvements using three sets of criteria that are adapted from architectural design quality literature: Functionality, Form and Aesthetic Values, and Building and Construction Quality.

2. LITERATURE REVIEW

2.1 Building Information Modeling (BIM)

Building Information Modeling (BIM) is a teamwork process using advanced technologies to create data modeling. It emerged as a shared resource of information and a collaborative process that applies advanced technologies to control the design and construction processes and to assess quality across the project life cycle phases. The National Building Information Modeling Standards (NBIMS) committee of USA defined BIM as a digital representation of physical and functional characteristics of a facility. It is a digital platform capable of creating virtual constructions (GSA, 2007). BIM helps project stakeholders to visualize all the project components in a simulated environment. The obtained model is a digital representation of the building that helps project stakeholders to extract needed information and take decisions during the project planning, design, construction, and operation processes (Azhar et al., 2012).

The Methodology of BIM implementation in the project life cycle should respect a specified workflow covering all concerned design trades within an organization: the development of the BIM Execution Plan (BEP), the Level of Development (LOD), the Project Development, the evaluation of BIM Quality, the 3D Design Coordination and Clash Detection, the Project Close Out and Archive - as shown in Fig.1: Implementation of BIM in the project life cycle.

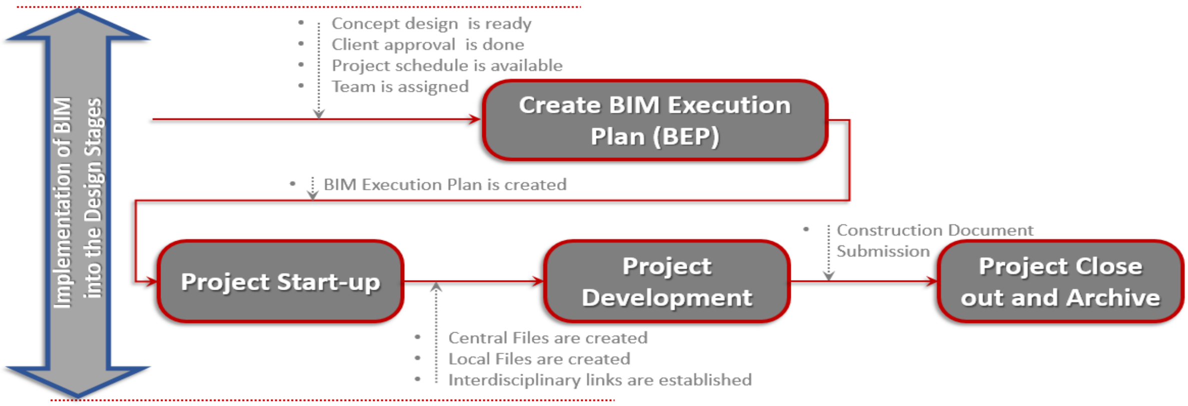

Fig.1: Implementation of BIM in the project life cycle

Reference: The Authors

All project stakeholders should be identified at the beginning of the project including the owner project team, the consultant team, statutory authorities and other involved parties. All of them should recognize the BIM policies, strategies, plans and protocols that considered vital management tools intended to aid each participant in tracking their works and services. Moreover, project phases, milestones, and BIM deliverables should be identified in BIM execution plan which defines the roles and responsibilities of the project team members.

The benefits of BIM is widely reflected on the society since the expected product is an eco-friendly construction consuming less energy and saving time and money(Olofsson et al., 2008). Consequently, BIM is more than a 3D modeling tool, it involves further dimensions related to a specific facility such as: Model-Based scheduling (4D) and Cost Estimation (5D), sustainability (6D), Facility Management (7D), Digital Fabrication and Parametric Design (8D).

Many BIM practices especially in some MENA countries are limited to the design stage. In these countries, technology adoption at large is still in a nascent stage; consequently, BIM is not widespread and did not reach full capacity. Although BIM can be used across a variety of applications separately, its full potential is demonstrated through shared information and interaction among all users. This requires a new kind of delivery system, which depends on cooperation (Korkmaz et al., 2010) .

In construction projects based on delivery systems, high integration level could enhance the outcomes (Chen et al., 2011; AIA, 2007). Integrated project delivery (IPD) is a delivery system based on collaboration (El Asmar et al. 2013). It aims to enhance project outputs through collaboration in order to achieve project objectives through risk and reward sharing and engaging the contractor from the earliest stages. It is more like a multilateral agreement. BIM and IPD have become interdependent and connected to information sharing (Eastman et al., 2011).

2.2 Quality in the Construction Process

The construction process is divided into three main phases, the design phase, the construction phase, and the operation and maintenance phase.

According to a study for the American Society of Civil Engineers (ASCE), quality in construction process, can be ensured when satisfying the requirements of the main stakeholders involved in the three stages mentioned above, which are the designer, the contractor, the owner and the public. The final goal of the construction process is to deliver a constructed facility to the owner. Thereby, owner's satisfaction is an integral part of the construction process (Ahola et al., 2018).

Managing quality in every phase of the construction process helps to enhance the building performance and make sure that that all parts of the project comply with the owner's requirements and are safe for the users. Total Quality Management (TQM) is an integrated effort dedicated to owner's satisfaction through continuous evaluation of all design parameters - as shown in Fig.2: Total Quality in the Construction Process (Arditi et al., 1997). Measuring owner's satisfaction enables stakeholders to discover the project strengths and weaknesses and make the right effort to improve its compliance with the preset design specifications (Gann et al., 2003) .

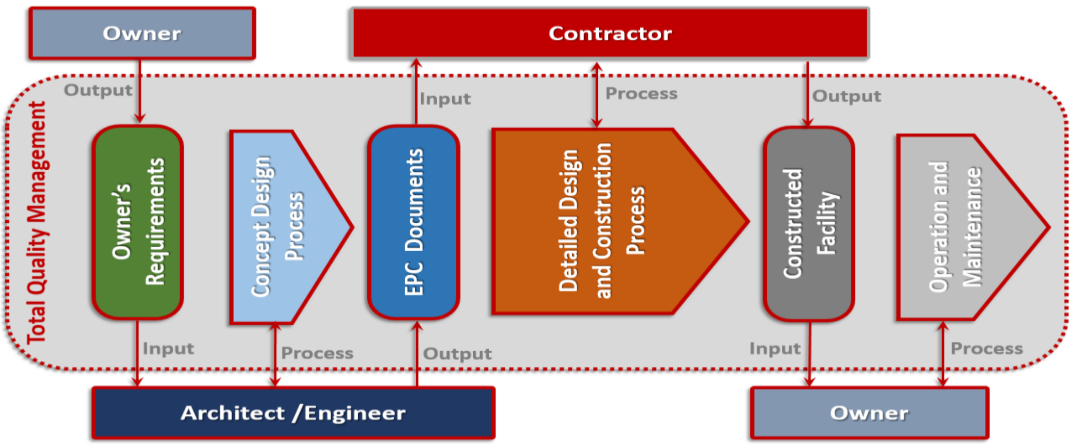

Fig.2: Total Quality in the Construction Process (Arditi et al., 1997)

The first phase in the construction process is the architectural design. It is a repetitive series of actions, with various parameters. Designers have to evaluate continuously the architectural design process (Aken van, 2003). This evaluation helps to obtain a constructed facility that satisfies customer's expectations. In this context, ISO 9000 describes design quality as the overall characteristics of a product or a service that satisfies the customers' requirements. Moreover, quality of architectural design is highly connected to aesthetic values; this is a subjective way of defining quality. Another definition adopts the functional point of view and relates quality to the project conformity with the preset requirements. Both approaches need to be in compliance with the legal framework (Arditi et al., 1997). To ensure architectural design quality, design professionals must specify standards within the project budget, since most of the time the major priorities for the owner are cost and time. Quality insurance has to be translated into specifications and documented to become obligatory to the contractor team .

Measuring design quality in architecture is a very complex process since some attributes are tangible parameters; others are less tangible and are hard to be measured. The challenge was always to develop a method to evaluate building quality by evaluating a wide variety of physical and emotional parameters to assess users' satisfaction. Evaluating building performance enables the designers to modify their plans and take particular measures to reach the required standard.

Experts conducted many researches and studies, invented several tools and adopted different certification programs with various rating systems to measure quality in design. Most of them counted on post occupancy evaluation or sustainability while respecting the environmental aspects. One of these tools is the Design Quality Indicator(DQI) which is a tool developed by the Construction Industry Council (CIC) – UK to assess, evaluate, and enhance the design quality of buildings. DQI makes the end-users feel involved in the decision making by expressing their needs and their requirements. For the design stakeholders, DQI sets a benchmark for quality standards and helps to produce constructions with high functionality and good impact (Farooqui et al., 2009) .

DQI has a conceptual framework based on Vitruvian principles named after the architect Marcus Vitruvius Pollio who emphasizes on three Values that a structure must attain functionality(use, access and space), Impact (form and materials, internal environment, Urban and social integration) and Build quality (performance, engineering systems and construction). The tool contains a set of sub-indicators deriving from the three above-mentioned indicators .

DQI appears to be the most comprehensive tool that covers all the aspects needed to evaluate the building quality. Thus, the research used DQI to assess the impact of using BIM on design quality.

3. ANALYZING THE RELATIONS BETWEEN BIM AND ARCHITECTURAL DESIGN QUALITY

While adopting Design Quality Indicator (DQI) to assess the impact of using BIM on design quality, the research analyses the relations between BIM and Architectural Design Quality in three steps in order to set several hypotheses needed to develop the conceptual model as follows:

3.1 Step 1: Analyzing the relations between BIM and Collaboration Capabilities ISC and CDC

Based on the literature Review conducted in previous section, BIM enables information exchange and encourages collaboration between project stakeholders in an integrating environment reducing communication cost, and construction waste. Thus, the following analyses highlight the relations between BIM application and collaboration capabilities ISC and CDC - as shown in figure 3.

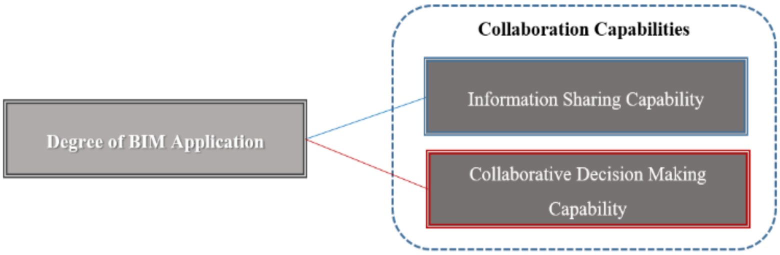

Fig.٣: the relations between BIM and Collaboration Capabilities ISC and CDC

Reference: The Authors

3.1.1 Impact of BIM on ISC

The technological progress led to a revolution in the information exchange, leaving a clear impact on the architectural process and the produced outcomes as well as on architects' role (Kalay 2006). BIM is a sharing information resource that facilitates decision taking while using several parameters related to the design, construction and implementation phases to create the data corresponding to the various stages of the project life cycle in a comprehensive way (Eastman et al., 2011). The use of BIM provides data exchange in order to facilitate the project management. Using BIM enabled systems ensures the continuity of information flow and improves the capabilities of all project participants to share accurate, complete, and coherent information.

The use of BIM is not limited to the use of modeling software such as Tekla and Revit, It also integrates the modeling software with a rich information platform (e.g., Bentley Project wise) and on-site testing technologies (e.g., RFID). Moreover, BIM has the ability to change the path in the construction industry; first, it is a unique way to incorporate data into design charts. Second, it can be simply standardized and third, it visualizes all information in practical virtual models. It helps to exchange useful information at the right time and in a consistent manner. (Tahrani et al. 2015). H1: A positive association exists between the Degree of BIM Application in a construction project and BIM enabled information sharing capability of the project's stakeholders.

3.1.2 Impact of BIM on CDC

Construction is a multidisciplinary process that necessitates the cooperation of many organizations depending on each other by establishing particular links between them in order to procure all the needed resources and to enhance performance (Winch, 2010). BIM promotes collaboration skills, by adopting a process that enables different sectors with variant goals and interdependent resources to cooperate and act together in order to solve critical problems requiring exceptional solutions that exceed their capabilities (Yan et al., 2014). The model represents visually all the phases of the project life cycle and encloses all the relevant information to facilitate decision making before, during and after construction. Hence, it helps to improve decision-making capabilities through coordination between the main responsible party and the other related parties to take optimal decisions. Therefore, BIM is considered as an inter-organizational tool that organizes the dependence between all the project participants by procuring collaboration capabilities between all the project stakeholders (Cao et al., 2017).

H2: A positive association exists between the Degree of BIM Application in construction project and the BIM enabled collaborative decision-making capability of the project's stakeholders.

3.2 Step 2: Analyzing the relations between ISC and the Architectural Design Quality Indicators

Information sharing is a main condition for knowledge sharing since it provides links between all project's participants in order to coordinate all activities. The research adopts Functionality, Form and Aesthetic Values, and Building and Construction Quality as Architectural Design Quality Indicators. Thus, the below analyses highlight the relations between the information sharing capability and the above mentioned indicators - as shown in Fig.٤: The relations between ISC and the Architectural Design Quality Indicators.

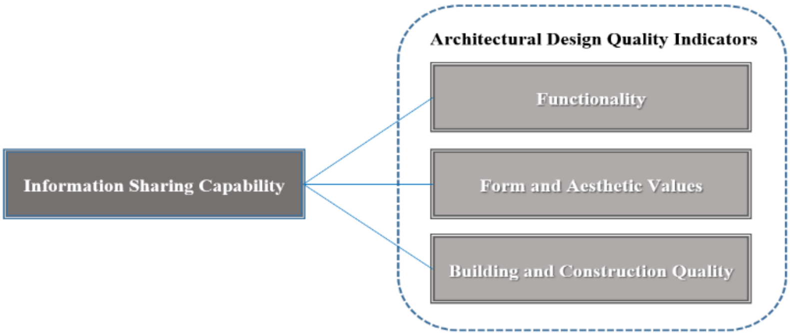

Fig.٤: The relations between ISC and the Architectural Design Quality Indicators

Reference: The Authors

3.2.1 Impact of ISC on Building Functionality

The implementation of BIM creates a resource of centralized shared information providing the necessary knowledge about a project in its design and operational phases. This advantage allows the data update and modification and reduces design conflicts (Rowlinson et al. 2010). By changing the specifications according to the design needs, the building turns to be more useful and fulfills its function. Information sharing helps to procure critical information about all designed spaces such as building accessibility for all users including people with special needs. Moreover, communicating and exchanging accurate information before the project implementation help to generate comfortable and livable spaces with the right dimensions. This pertinent storage information system allows all specialists to interpret data without confusion and provide well-arranged spaces, thus, increasing the building functionality (Onyenobi et al., 2010). H3a: Project's stakeholders with greater BIM enabled information sharing capability are more likely to achieve a greater extent of building functionality improvement.

3.2.2 Impact of ISC on Form and Aesthetic Values

BIM is conceptualized as an exchanging information process that provides communication between different stakeholders and participants involved in the design process. The information exchange is done continuously through a digital model containing all the relevant information with a developed evaluation system to reduce errors. Design quality is the primary concern for architects, who pay a great importance for the aesthetic values. In order to measure design quality a number of tangible and intangible indicators must be identified. Quality measurement allows cost and time reduction, transparency, and customer satisfaction. Using BIM combined with quality assurance and quality control processes allows continuous evaluations and enhances the decision-making process (Rajendran, 2015). The information sharing capability provided through BIM use supports architectural design and promotes aesthetic values. Consequently, it improves building quality (Motta et Al., 2017). H3b: Project's stakeholders with greater BIM enabled information sharing capability are more likely to achieve a greater extent of form and aesthetic values improvement.

3.2.3 Impact of ISC on Building and Construction Quality

The use of advanced technologies such as Internet, electronic data, wireless application protocol, mobile computing and extensible mark-up language combined with significant information allows all parties to improve the information processing capabilities and enables architects to create virtual designs before the construction stage. BIM offers a digital platform to generate virtual buildings (GSA, 2007). It gives the potential to make better analysis for basic engineering data in particular data related to building efficiency and safety (Gerrish et al., 2017).

BIM allows interrelation between all building components transforming the construction to a more intelligent process able to be modified according to the client needs (Kalay 2006). To guarantee the performance of the project, the involved participants or stakeholders should be provided with relevant information regularly, in parallel with the implementation of each stage of the project; the digital model should, then, be reviewed and updated by including the new corrected information or any missing data.

This approach of maximum data use facilitates the management of the engineering systems and procures control to the project's construction phases. Based on the above, information sharing enhances building performance, provides better safety precautions and raises building's efficiency and durability, thus, it improves building and construction quality. H3c: Project's stakeholders with greater BIM enabled information sharing capability are more likely to achieve a greater extent of building and construction quality improvement.

3.3 Step 3: Analyzing the relations between CDC and the Architectural Design Quality Indicators

BIM provides a platform of information that enables the collaboration between the decisions makers all over the project lifecycle. It has the ability to improve task efficiency and raise task effectiveness by saving time, lowering cost and using appropriate resources. The below analyses highlight the relations between the collaborative decision capability and the Architectural Design Quality Indicators - as shown in figure Fig.٥: The relations between CDC and the Architectural Design Quality Indicators.

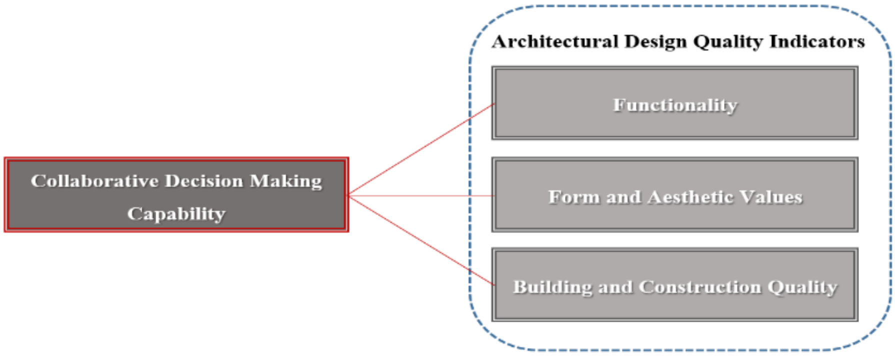

Fig.٥: The relations between CDC and the Architectural Design Quality Indicators

Reference: The Authors

3.3.1 Impact of CDC on building functionality

BIM implementation facilitates the communication between traditionally fragmented parties in the construction process. Increased high-quality collaboration can improve business performance (Cao et al., 2011). Final decisions are taken after a collaborative participation of all stakeholders with significant contributions (Krygielet al., 2008). This teamwork integrates different perceptions from different viewpoints since each participant has his own and unique way to find the optimal solution to solve a determined problem (Zaraté et al., 2013). Projecting this approach on building design, several stakeholders determine by their decisions the level of a building functionality. Transforming function into form and applying functional analysis to design processes has always raised a critical topic in Architectural Theory. If we consider the famous equation of Louis Sullivan, "Form follows Function" we can easily realize the importance of function fulfillment in architecture. Architects are the main responsible of the spaces usefulness, since the sizes of the rooms, the heights of the ceilings and the ease of entering each living area must carefully match the function of the building. In addition, raising awareness about respecting building's functionality has raised the issue of a good design adapted to human needs allowing people to live in a comfortable environment, with improved conditions. The construction facility is successful when it satisfies users emotional, cognitive, and cultural needs in addition to technical requirements due to the building type (Akadiri et al., 2012). H4a: Project's stakeholders with greater BIM enabled collaborative decision-making capability are more likely to achieve a greater extent of Building Functionality improvement.

3.3.2 Impact of CDC on Form and Aesthetic Values

In construction, 'quality' does not have the same meaning as in the industrial sector due to the particularity of the project location and the complexity of the design process that encloses different stages of the building lifecycle (Arditi et al., 1998). Design and construction processes depend on collaborative capabilities from different backgrounds. The use of digital models to support these processes improves engineering analyses and provides integration through visualization of all design components (Bernstein et al., 2004). Each error has an influence on the design schedule and it will cost money, waste time and affect design quality, therefore it is useful to predict the building performance by doing early evaluations through analysis-simulation tools.

Adopting BIM helps to integrate design and construction phases. The end-product of this integration is a high quality project executed with the optimal cost and time (Eastman et al., 2011). Furthermore, BIM provides visual communication between the different stakeholders and experts. As a result, all the involved participants can view the project layouts, put their comments, do faster analyses, suggest critical solutions, and recommend the best technologies to be adopted. Consequently, design errors will be minimized and construction rework will be reduced, increasing tasks effectiveness and producing high-quality outcomes (Chang, 2017).

H4b: Project's stakeholders with greater BIM enabled collaborative decision-making capability are more likely to achieve a greater extent of Form and aesthetic values improvement.

3.3.3 Impact of CDC on Building and Construction Quality

Using BIM to support design offers a wide platform of information storage. It provides knowledge sharing and enables the collaboration of the decisions makers in all design phases, thus BIM promotes design improvement (Krygiel et al., 2008). BIM offers an integrated construction system with a wide set of parameters accessible for all involved stakeholders. The system affects the building's performance, facilitates the management of the adopted structure systems, and enables the control of all construction phases.

The design of the building plays an essential role in its energy performance since its energy consumption is determined during the design stage (Bordass, 2004). In this stage, BIM allows a building energy modeling (BEM), which is a simulation to analyze the performance of the building energy after setting building's description and all useful information. Measuring improvements in energy performance is a very difficult process because of the uniqueness of each project, but the reuse of common environmental data in similar projects helps to improve the energy performance (Arayici et al., 2011).

BIM has the ability to develop a visual model that can be used from early design stages of the building to construction occupancy and maintenance, allowing the control of all construction phases. Moreover, the stakeholders involved at each stage of the design must be indicated to coordinate together and change the parameters according to the design benefit. The requirements of these stakeholders given in early stages are transformed into basic information or input stored, analyzed and shared via BIM. These interventions specify the design progress and help to improve efficiency in the construction management by increasing the collaboration level between clients, Architects, Engineers, contractors and all involved experts. The illustration of the building with all the relevant details gives a clear model of the output in its expected real conditions and enhances safety and durability.

H4c: Project's stakeholders with greater BIM enabled collaborative decision-making capability are more likely to achieve a greater extent of building and construction quality improvement.

4. PROPOSED CONCEPTUAL MODEL

Based on the above literature review and analyses, the resulting hypotheses are summarized in the below table:

Table 1: Resulting Hypotheses Summary – Reference: The authors

Relations between the Proposed Model Variables	No.	Resulting Hypotheses
Impact of BIM on ISC	H1	A positive association exists between the Degree of BIM Application in a construction project and BIM enabled information sharing capability of the project's stakeholders.
Impact of BIM on CDC	H2	A positive association exists between the Degree of BIM Application in construction project and the BIM enabled collaborative decision-making capability of the project's stakeholders
Impact of ISC on building	H3a	Project's stakeholders with greater BIM enabled information sharing capability are more likely to achieve a greater extent of Building

functionality		Functionality improvement.
Impact of ISC on form and aesthetic values	H3b	H3b: Project's stakeholders with greater BIM enabled information sharing capability are more likely to achieve a greater extent of Form and aesthetic values improvement.
Impact of ISC on building and construction quality	H3c	Project's stakeholders with greater BIM enabled information sharing capability are more likely to achieve a greater extent of building and construction quality improvement.
Impact of CDC on building functionality	H4a	Project's stakeholders with greater BIM enabled collaborative decision-making capability are more likely to achieve a greater extent of building functionality improvement.
Impact of CDC on form and aesthetic values	H4b	Project's stakeholders with greater BIM enabled collaborative decision-making capability are more likely to achieve a greater extent of form and aesthetic values improvement.
Impact of CDC on building and construction quality	H4c	Project's stakeholders with greater BIM enabled collaborative decision-making capability are more likely to achieve a greater extent of building and construction quality improvement.

The hypotheses deduced from the analyses led to develop a conceptual model that links BIM to the inter-organizational collaboration capabilities in terms of ISC and CDC. This model relates these capabilities to architectural design quality indicators. The resulting conceptual model is illustrated - as shown in Fig.٦ : The proposed relation between the degree of BIM application and architectural design quality indicators below.

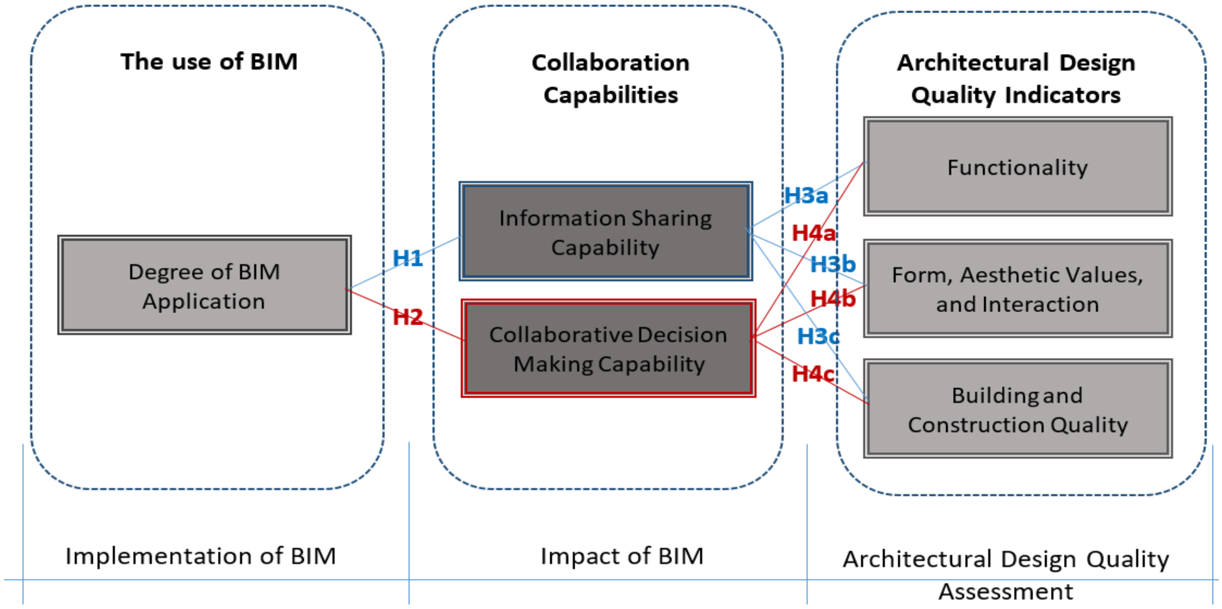

Fig.٦ : The proposed relation between the degree of BIM application and architectural design quality indicators
Reference: The Authors

The above conceptual model shows that BIM could have a direct impact on improving information exchange and collaborative decision-making capabilities between the project's stakeholders. BIM is perceived as an inter-organizational tool that arranges the relations between all the project parties. Moreover, the use of BIM can produce high-quality outcomes since it helps in raising building's efficiency and durability. BIM has reformed the buildings design, construction, and operation. It allows all project participants to share accurate and coherent information while increasing tasks effectiveness.

The improvement of information sharing and collaborative decision-making capabilities between all project's stakeholders lead them to interpret data and design well-organized spaces, while improving the building functionality, promoting aesthetic values, reducing design errors, and enhancing building and construction quality.

5. CONCLUSION

The results that could be obtained from the adoption of BIM to enhance design quality, represent a strong motivation for practitioners, decision makers and academic.

For practitioners, the research highlights the importance of using BIM to increase the information sharing and collaborative decision making capabilities of the design and construction team and the positive impact of such increment on the building quality.

For decision makers, the research encourages them to amend specific sections of the Lebanese building codes and regulations in order to make the BIM model submission one of the essential deliverable to get permit accordingly. They can even oblige the owners, consultants and contractors of large scale developments to adopt the use of BIM with high level of application. The statutory authorities can also motivate the Owners, Consultants and Contractors to use BIM in the design, construction and operation processes by offering tax incentives.

For academics, it enriches the existing models by including a long-term view into the mediation role played by information sharing and collaborative decision-making capabilities. Hence, it opens the way to integrate the use of BIM with the Architectural Design and Execution Courses and encourages students to be engaged in training programs in Architectural and Engineering companies that are using BIM. Besides, the research opens different ways for new research streams .

While assessing if the use of BIM can enhance the architecture design quality, the research contributes to the BIM literature by presenting a new conceptual model that links BIM enabled information sharing and collaborative decisions capabilities to the building design quality

Finally, the findings of this research contribute to the stream of literature tackling BIM by showing that the use of BIM offers a wide range of benefits to the construction stakeholders in terms of enhancing the design quality through improving the process of the data management and transfer.

6. FUTURE WORK

The research showed the existence of a relation between BIM adoption and the improvement of three indicators: functionality, form and aesthetic values, and building and construction quality. It would be noteworthy to conduct a quantitative analysis to assess the impact of the degree of BIM implementation on each of these indicators while using ISC and CDC as mediators. Furthermore, it would be interesting to quantitatively test the validity of the proposed conceptual model in different geographical regions to depict any possible deviations in the results that could be due to cultural differences or variations in construction regulations.

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