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Building Information Modeling and Building Knowledge Modeling in Project Management

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Background: The key element for the success of construction projects in the era of technology and information is knowledge. Knowledge management in the construction sector has become a necessary and vital matter, starting with the planning stage, designing, implementing and ending with operation and maintenance stage. One of the most prominent features of knowledge in the construction sector is the building knowledge modeling (BKM). **Problem**: Although the design stage is considered one of the most important stages of the construction project in terms of eliciting the knowledge element, designers suffer from poor knowledge management, as well as their inability to exploit the capabilities and benefits of building information modeling (BIM), especially knowledge management. **Objective**: The main aim of this study is to present a conceptual model that integrates the basic principles of knowledge management with contemporary principles of BIM in the design stage and has the ability to store, classify and share the knowledge generated from past designs into future projects. **Methodology**: The research methodology is constructed on reviewing the pillars of the proposed conceptual model, namely: BKM parameters, BKM library, and BKM clash detection system, then a hypothetical case to prove the validity of the proposed conceptual model using Basmaya residential complex project in the Republic of Iraq is presented as a case study. **Results**: New four definitions

are introduced: client knowledge, context knowledge, standards knowledge and technical knowledge. The conceptual model proposed in this study has shown great ability and high efficiency in improving and developing knowledge management in the design stage of buildings and projects. In addition, the knowledge stored in the BKM library can be reused in designing new projects in the future. **Novelty**: The conceptual model has the ability to update constantly itself over time by sharing the knowledge of designers, suppliers and other stakeholders.

Keywords: building information modeling (BIM), building knowledge modeling (BKM), client knowledge, context knowledge, standards knowledge, technical knowledge.

1. Introduction

The idea of building information modeling (BIM) and its use in the construction industry has been conceptualized for less than forty years. The term "building modelling" was documented for the first time, in the same connotation of the present use of the term "building information modelling", in Aish's article titled "Building modeling: the key to integrated construction CAD" in 1986. However, the term "building information model" had not been documented until van Nederveen and Tolman published their paper titled "Modeling multiple views on buildings" in 1992 [1].

Basically, the concept of building information modeling can be defined as the process of representing the actual reality in the framework of virtual reality, and this is done through the integration between the design processes of the building with a comprehensive database. Thus, adequate information to simulate the characteristics of each element of the building are obtained, and this helps in reaching the optimized solutions for the structure's various aspects, such as the design of the building, cost control, duration control, the sustainability of the structure and others, before starting the actual construction operations of the building [2].

The importance of BIM is highlighted by its ability to deal with an unlimited number of dimensions. After developing the three-dimensional model of the building, the fourth dimension can be added to represent the time dimension, the fifth dimension represents the cost dimension, the sixth dimension represents the building's sustainability dimension, the seventh dimension represents the facilities management dimension, and the eighth dimension represents the prevention through design (PtD) dimension, As there are more dimensions still in the process of discovery, the ninth dimension can be considered as the BKM [3].

BKM integrates knowledge management principles with BIM tools to formulate a model that helps consultants and designers to manage knowledge in the field of building design [4]. The concept of BKM is considered a new and modern

topic in the field of project management, despite the limited studies that dealt with it. In 2009 and 2010, the first two studies on it were presented [5, 6].

Three years later, the first conceptual model for the BKM application was developed to be able to export the lessons learned from BIM users to the knowledge repository. This contribution is considered positive and important for the development of BKM [7].

In 2014, two vital and important studies were presented in the field of BKM [8, 9], as the authors put the correct concept of BKM into the real-life context of building design and construction projects.

Table 1 shows the essential differences between the computer-aided design (CAD), BIM and BKM for some components in buildings, as it is noticed that the BIM model includes the same components of the building drawn by the CAD adding to it the information of these components, while the BKM model includes the same components of the building drawn by the BIM model adding to it adequate knowledge of these components.

Table 1. Differences between CAD, BIM and BKM.

Component	Definition	Element of Windows	Element of Slab
CAD	2D + 3D	geometrical dimensions	geometrical dimensions
BIM	2D + 3D + information	information, manufacturer	information, load
BKM	2D + 3D + information + knowledge	knowledge, end user feedback	knowledge, structural standards

2. Research importance

Knowledge management in construction projects is considered a very effective method, as it has become a common concept in the construction industry, and because it contributes to improving performance and efficiency when designing and implementing projects through the use of various techniques, methods, and processes that lead to the organizational optimization of knowledge.

The construction industry in the world is facing continuous and new challenges and threats, and in order for construction companies to remain at the forefront, they must accept these challenges, BKM is one of the most important challenges that provide a competitive advantage to contracting companies.

The effective use of BKM during the design and implementation of construction projects contributes to the development of the knowledge of the stakeholders (investors, designers, contractors, suppliers, etc.) in their future projects.

It is known that BIM gives an effective value to each stage of construction projects. However, BKM gives unique advantages to projects, as it represents the first step to automating processes, and the integration of BIM and BKM can

play a distinct role in complex activities and routine activities by managing all project information.

3. Research objective

The rapid and steady growth of BIM in all construction projects around the world requires its integration with BKM in all stages of the construction project.

In fact, there were limited attempts by researchers to achieve integration between the two models, but all of them failed [7, 8]. Hence, the main aim of this study is to present a conceptual model that integrates the basic principles of knowledge management with contemporary principles of BIM, and has the ability to store, classify and share the knowledge generated from the projects that are currently implemented for future projects.

4. Research methodology

The research methodology includes three main steps:

1) The first step: manage design knowledge through an attempt to divide the knowledge into a specified number of categories;
2) The second step: review the pillars of the proposed conceptual model, namely: BKM parameters, BKM library, and BKM clash detection system;
3) The third step: present a hypothetical case to prove the validity of the proposed conceptual model.

4.1. Manage design knowledge

By reviewing previous studies on the topic of design knowledge management, we found that there are limited attempts to classify design knowledge. Zhang *et al.* [10] divided knowledge into two main types: explicit knowledge, which is written knowledge recorded in various documents, and tacit knowledge, which is knowledge acquired through experience. Tan *et al.* [11] classified knowledge into three categories: general knowledge, specific knowledge, and process knowledge.

To obtain correct and accurate information regarding the classification of design knowledge in consulting firms working in the field of construction project management, and given the health conditions that the world is going through due to the Corona pandemic, the researchers in this study used the method of personal interviews through the Zoom platform. The personal interview approach is very important in the academic and project management fields [12–16]. Three experts were invited, whose qualifications are shown in Table 2, to express their views on design firms' different types of knowledge. The meetings were held

Table 2. Experts detail and answers.

#	Experts	Engineering field	Experience years	Knowledge provided
1	Project Manager	Civil	27	Problems solved and lessons learned
2	Designer	Architecture	23	Contextual knowledge & standards
3	General Contractor	Mechanics	40	Client knowledge

through the Zoom platform on August 12th and 13th, 2020, and the researcher reviewed various design knowledge categories with experts. Next, the discussion and inquiries section was opened to answer all the questions raised in the meetings.

The first interviewee, who works as a project manager with 27 years of experience in the field of civil engineering, narrated a real incident that occurred in a construction project in Baghdad, the capital of the Republic of Iraq, which sheds light on one of the important types of knowledge in design work. "After the completion of the project designs for the Water Treatment Plant (WTP) and before starting the implementation work, it was discovered that the Ministry of Works and Municipalities did not obtain approval for the project designs, as the official body responsible for this type of project, and if we knew this, we would have saved a lot of effort, time and money". Therefore, official approvals and check reports of design can be considered an important part of design knowledge that comes from practical experience. The second interview was with the designer, with 23 years of experience, who explained that design contextual knowledge is an essential and fundamental issue for all designers due to a lot of effort and time spent on research and investigation to acquire this knowledge. He also pointed out to international design standards as an integral part of the knowledge. Finally, the third interview was with one of the experts in construction projects who is a general contractor (GC) and has an estimated 40 years of experience. The third interviewee explained that the lessons learned from previously completed projects, such as problem-solving, the benefits of meetings and the best ways to work during the design phase of the project, they all represent the essence of client knowledge.

Through the results of the personal interviews, design knowledge can be divided into four classifications, all of which are related to the project design, as shown in Fig. 1, as follows:

1) client knowledge,
2) context knowledge,
3) standards knowledge,
4) technical knowledge.

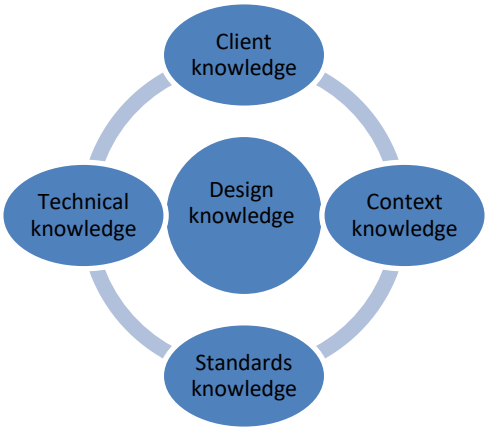

Fig. 1. Classification of project design knowledge.

1. Client knowledge: A database must be built for all clients and all companies working in the construction sector, and it includes all data and information about clients' policies, priorities, needs and criteria for their evaluation with all the main details of each company, and this will help save a lot of time and effort spent by designers in coming to know their clients and meeting their requirements.
2. Context knowledge: The geographical location in which the construction project is being constructed, which fundamentally affects the design of the project, requires building a knowledge base called knowledge of the context, and this database includes data on the architectural patterns of construction projects as well as their urban patterns, infrastructure networks, laws, legislation, social traditions, etc. Therefore, contextual knowledge will be categorized according to the geographic location of the cities, thus providing contextual information to designers and consultants.
3. Standards knowledge: The third class of design knowledge are design standards, and it refers to all architectural standards, construction standards, health and sanitary standards, mechanical standards, electrical standards, information and communication technology standards, and finally, occupational health and safety standards. These standards are either local standards related to the country in which the construction project will be built or international standards.
4. Technical knowledge: Technical knowledge includes lessons learned from all designers working in construction projects with recording all problems and solutions for previous designs, in addition to indicating the best and finest designs previously completed to be used in future projects, and thus technical knowledge can be considered a comprehensive library of all aspects of technical design.

4.2. BIM knowledge parameters

The boundary between CAD and BIM is the parametric element, so it is known to designers that CAD is a matter of geometry only (lines only), while BIM is an expression of information related to geometry (descriptive information). These differences can be illustrated as in Fig. 2, which illustrates the information specific to the element (door) drawn in the Autodesk Revit. It is noticed that each parameter has a clear description and a numerical value, such as width, length, the material of manufacture, etc.

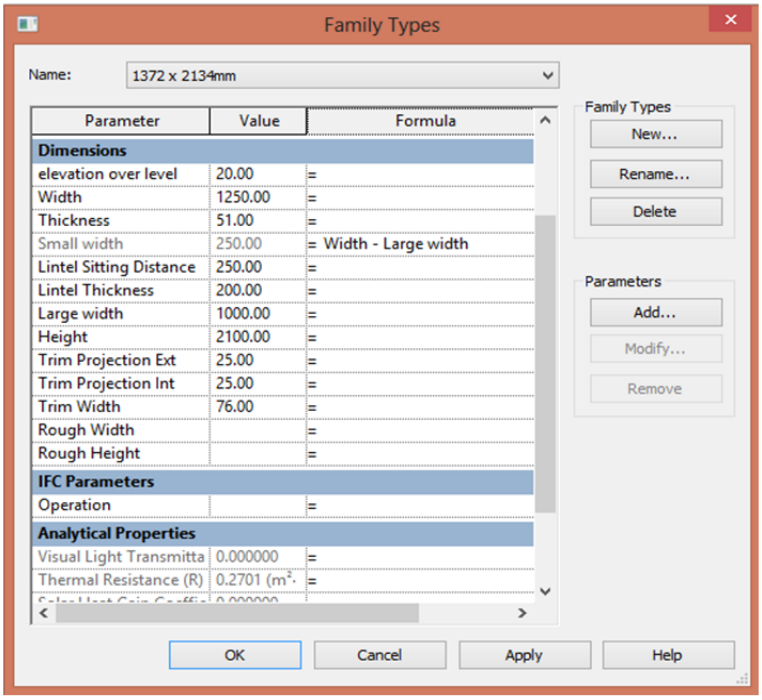

Fig. 2. Parameters of door component.

Based on the four categories of knowledge (client knowledge, context knowledge, standards knowledge, and technical knowledge), the knowledge element can be added or linked to the various components that make up the building within the BIM model, using the parametric classification in the Autodesk Revit.

In this study, four types of knowledge parameters were used (client, context, standards, and technical) as shown in Fig. 3, which reveals two types of BIM parameters: the current information parameters and the proposed knowledge parameters.

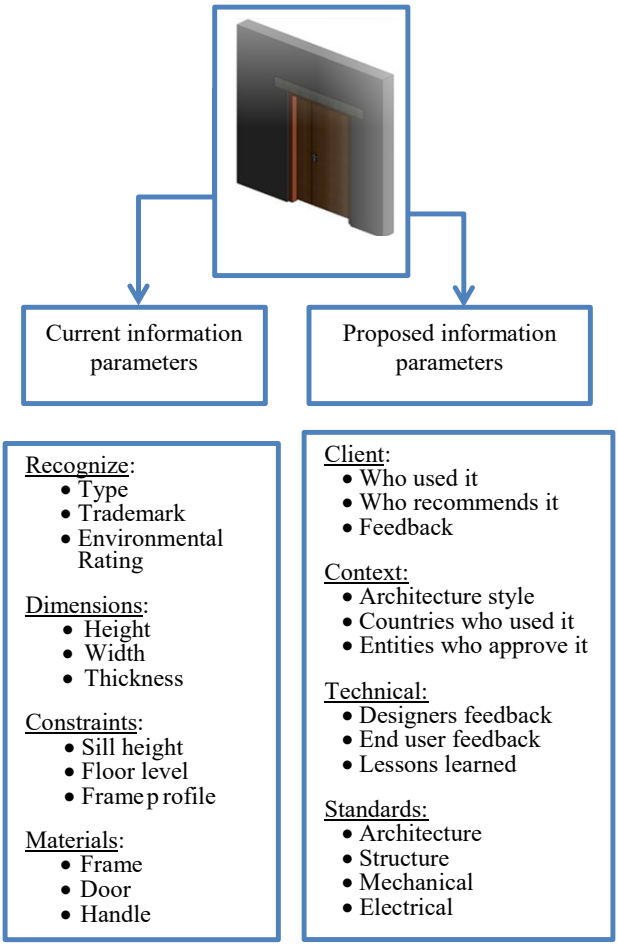

Fig. 3. Differences between the current and proposed information parameters.

4.3. BKM library and BIM library

There are many BIM libraries online, of which the most important and popular ones are shown in Table 3.

Table 3. BIM libraries.

BIM library	Website
BIMobject	https://info.bimobject.com/
NBS National BIM Library	https://www.nationalbimlibrary.com/en/
bimstore	https://www.bimstore.co/
BIMcomponents	https://bimcomponents.com/

All those interested in building information modeling such as designers, consultants, suppliers, manufacturers and organizations around the world can share their unique building components (BIM components and BIM objects) with others so that designers can benefit from them in future projects. BIM libraries are setting a unique standard in the world of construction by producing advanced solutions for managing BIM objects and sharing them with beneficiaries through cooperation between manufacturers and construction companies.

The concept of a BKM library is exactly the same as that of a BIM) library and the difference is that, in the BKM library, knowledge is stored instead of information in a global repository on the Internet. Consequently, a BKM library must be developed to be available to all designers. This is done through increasing the inputs the library receives from all stakeholders (clients, designers, suppliers, contractors, project managers, and others), as well as working to improve, maintain and classify this library in the light of knowledge management techniques and their preservation, also, available to all beneficiaries.

4.4. Knowledge clash detection

Clash detection in construction projects is one of the most important aspects of BIM. It occurs when different designs of the construction, electrical, sanitary, mechanical and other works are not coordinated in one place inside the building, As a result, the collision occurs, which leads to the delay in the completion of the project. Therefore, BIM can be used to prevent conflict by knowledge using a compatibility test by advanced software, as conflicts between design parameters are detected and defined automatically by comparing the design with the knowledge stored within the BKM library, and as shown in Figs 4 and 5, where the designers are informed of the conflicts immediately, and they work on

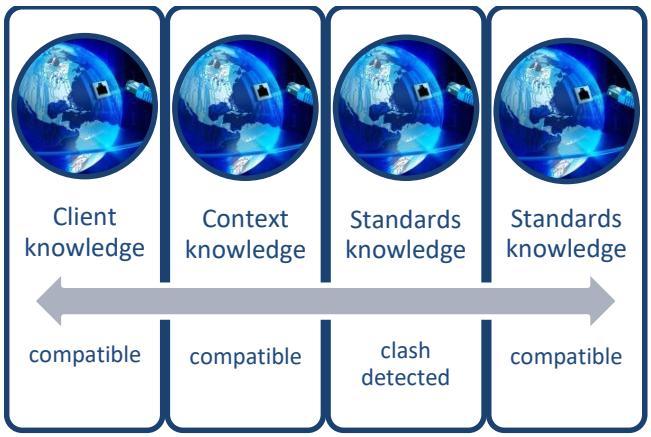

Fig. 4. Knowledge clash detection.

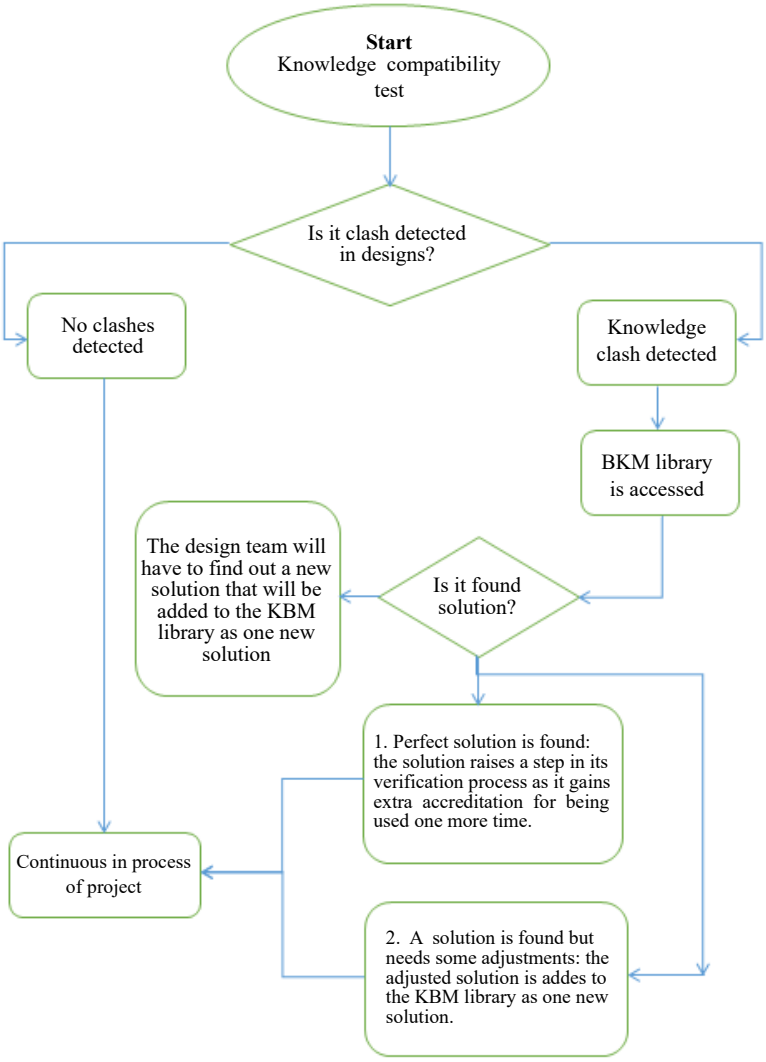

FIG. 5. Knowledge compatibility test.

solving it through solutions that are stored in the knowledge base of the BKM library from previously implemented projects, as the following are:

1) A perfect solution is found: the solution raises a step in its verification process as it gains extra accreditation for being used one more time.
2) A solution is found but needs some adjustments: the adjusted solution is added to the BKM library as one new solution.
3) No solutions are found: the design team will have to find a new solution that will be added to the BKM library as one new solution.

4.5. Hypothetical design as a case study

This part of the study is the conceptual model for a hypothetical design project. In this study, the Basmaya residential complex project in the capital, Baghdad, Republic of Iraq, was chosen, and its details are described below.

The Basmayah City project (Fig. 6) is the first of its kind and the largest in the history of Iraq in terms of size, level of services and infrastructure provided in it, as the new city of Basmayah is an integrated residential complex located 10 km southeast of the capital Baghdad, Iraq, on International Road No. 6 – a link between the capital, Baghdad, and Wasit Governorate, on an area of 1830 hectares. This project consists of 100 000 housing units, and it also includes an integrated infrastructure network of water and electricity, and schools and recreational and commercial complexes. The cost of constructing the complex is USD 7.75 billion. The project is being implemented by the Korean Hanwha Engineering and Construction Company, which works in the field of construction around the world, with a completion period of seven years. The designer's team manages a BIM for the Basmaya residential project with detailed parameters of all the components of the project's buildings by making use of the BIM and BKM libraries as follows:

1) Context knowledge: BIM must include all designs for residential complex projects in Iraq, making sure that the building component (main entrance door) is available in Iraq or can be imported, and also making sure that this component has been used in the past construction projects in Iraq, and has been approved by the official authorities.
2) Client knowledge: One of the advantages of the conceptual model in this study is that it contains all the construction projects owned by the Na-

Fig. 6. The layout of the Basmayah City project (http://sulcci.com/arabic/details.aspx?=hewal&jmare=303&Jor=1).

tional Investment Commission – Iraq, with all observations, problems and solutions that they faced upon design and implementation, which help designers when designing new projects similar to those implemented.

3) Standard knowledge: The conceptual model in this study confirms the existence of local standards for the design of various building components (main entrance door) as well as European and international standards while ensuring that the design standards developed by designers are compatible with local, European and international standards in terms of dimensions and quality of materials used and others.
4) Technical knowledge: This part of the conceptual model deals with technical knowledge by fixing details of knowledge related to building components (main entrance door) such as recommendations of designers, suppliers, or implementers of those components in the past, which helps this part of knowledge to grow and develop over time.

Upon completion of all project designs, these designs are examined and verified through a compatibility test in order to discover conflicts and clashes and make recommendations to resolve those conflicts by using the BKM library, which provides a wide variety of solutions and recommendations.

5. Conclusions and recommendations

Despite the complex nature of construction project management and the rapid development of construction techniques and methods, there are still multiple gaps in the construction industry, especially in the design stage. The lack of a clear philosophy of knowledge management for designers during the preparation and presentation of designs in construction projects is one of those gaps.

The desired benefit of knowledge management is the creation, organization and exchange of knowledge within the BKM library to improve and develop building design processes and reduce effort, time and costs.

The importance of this study is highlighted in presenting BIM technology as a growing and renewable tool to improve the design phase of buildings and projects by adopting a conceptual model for building knowledge modeling, with a focus on three basic aspects, which are BKM parameters, BKM library and BKM clash detection system.

The conceptual model proposed in this study has shown great ability and high efficiency in improving and developing knowledge management in the design stage of buildings and projects. In addition, the knowledge stored in the BKM library can be reused in designing new projects in the future, and the conceptual model has the ability to constantly update itself over time by sharing the knowledge of designers, suppliers and other stakeholders.

The current study recommends the necessity of adopting the developed conceptual model for construction companies, as well as training designers and developing their capabilities, and on the future research side, the current study recommends the necessity of conducting a future study to convert the conceptual model into a real application in BIM platforms, as well as conducting another study to discover other aspects of design knowledge.

The availability of data

The study findings supported by the data can be obtained from the corresponding author upon requests.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Author contributions

Faiq M.S. Al-Zwainy conceived the presented idea, contributed to sample preparation and wrote the manuscript. Ibrahim Farouq Varouqa contributed to research concept and design, and data collection and assembly. Nidal A. Jasim contributed to data analysis and interpretation and supervised the findings of this work. Hadi Salih Mijwel Aljumaily discussed the results and contributed to the final approval of the article.

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