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Practical use of computational building information modeling in repairing and maintenance of hospital building- case study

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Abstract. Computational Building Information Modeling (BIM) is an intelligent 3D model-based process that provides architecture, engineering, and construction professionals the insight to plan, design, construct, and manage buildings and infrastructure more efficiently. This paper aims at using BIM in Hospitals configurations protection. Infrastructure projects are classified as huge structural projects taking advantage of many resources such as finance, materials, human labor, facilities and time. Immense expenses in infrastructure programs should be allocated to estimating the expected results of these arrangements in domestic economy. Hence, the significance of feasibility studies is inevitable in project construction, in this way the necessity in promoting the strategies and using global contemporary technologies in the process of construction maintenance cannot be neglected. This paper aims at using the building information modeling in covering Imam Khomeini Hospital's equipment. First, the relationship between hospital constructions maintenance and repairing, using the building information modeling, is demonstrated. Then, using library studies, the effective factors of constructions' repairing and maintenance were collected. Finally, the possibilities of adding these factors in Revit software, as one of the most applicable software within BIM is investigated and have been identified in some items, where either this software can enter or the software for supporting the repairing and maintenance phase lacks them. The results clearly indicated that the required graphical factors in construction information modeling can be identified and applied successfully.

Keywords: Computational Building Information Modeling (BIM); repairing; maintenance; hospital construction

1. Introduction

Nowadays, constructions own a notable part of the infrastructures and in many ways define and shape the environment people live in. The increasing demands on structures and infrastructure adapting to an ever-changing social landscape is further rising the requirement for novel and improved engineered materials and solutions to ensure the optimal exploitation of resources, and foster a more sustainable use of owner's assets. Many researches have been conducted to explore the determinants of

preference for familiarity or preference for novelty in individuals for structures (Moghaddam *et al.* 2009, Fanaie *et al.* 2012, Fanaie and Dizaj 2014, Mohammadhassani *et al.* 2014a, Mohammadhassani *et al.* 2014b, Mohammadhassani *et al.* 2014c, Shariati 2014, Shariati *et al.* 2014a, Shariati *et al.* 2014b, Toghroli Ali *et al.* 2014, Fanaie *et al.* 2015, Ghassemieh and Bahadori 2015, Khorramian *et al.* 2015, Shah *et al.* 2015, Shariati *et al.* 2015, Bahadori and Ghassemieh 2016, Fanaie *et al.* 2016a, Fanaie *et al.* 2016b, Khanouki *et al.* 2016, Safa *et al.* 2016b, Safa *et al.* 2016c, Shah *et al.* 2016a, Shah *et al.* 2016b, Shah *et al.* 2016c, Shahabi *et al.* 2016a, Shahabi *et al.* 2016b, Shariati *et al.* 2016, Tahmasbi *et al.* 2016, Toghroli *et al.* 2016). The extension of computer technology has created a huge revolution in designing and constructing projects. Recent computational methods (Toghroli Ali *et al.* 2014, Aghakhani *et al.* 2015, Mohammadhassani *et al.* 2015, Toghroli 2015, Mansouri *et al.* 2016, Safa *et al.* 2016a, Safa *et al.* 2016b, Safa *et al.* 2016c, Toghroli *et al.* 2016, Khorami *et al.* 2017a, Khorami *et al.* 2017b, Khorramian *et al.* 2017, Mansouri *et al.* 2017, Heydari and Shariati 2018, Sedghi *et al.* 2018, Shariat *et al.* 2018, Toghroli *et al.* 2018a, Zandi *et al.* 2018) and experimental researches (Hamidian *et al.* 2012, Jalali *et al.* 2012, Kazemi *et al.* 2012, Momenzadeh 2012, Shariati *et al.* 2012a, Shariati *et al.* 2012b, Shariati *et al.* 2012c, Shariati *et al.* 2012d, Shariati *et al.* 2012e, Sinaei *et al.* 2012, Mohammadhassani *et al.* 2013, Shariati *et al.* 2013, Momenzadeh 2017, Momenzadeh *et al.* 2017a, Momenzadeh *et al.* 2017b, Momenzadeh *et al.* 2017c, Shen *et al.* 2017, Stanojevic *et al.* 2017, Andalib *et al.* 2018, Ismail *et al.* 2018, Momenzadeh and Shen 2018, Nasrollahi *et al.* 2018, Nosrati *et al.* 2018, Paknahad *et al.* 2018, Toghroli *et al.*

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2018b, Wei *et al.* 2018, Ziaei-Nia *et al.* 2018) have been used for this purpose. With the development of construction industry, the high deficiency to facilitate communication, concept sharing between the stakeholders and other project members, the need to softwares for the aim of project control, computer drawing softwares and so on, have been extended (Kheyroddin *et al.* 2008, Shariati 2008, Arabnejad Khanouki *et al.* 2010, Shariati *et al.* 2010, Arabnejad Khanouki *et al.* 2011, Daie *et al.* 2011, Hamidian *et al.* 2011, Shariati *et al.* 2011a, Shariati *et al.* 2011b, Shariati *et al.* 2011c, Shariati *et al.* 2011d, Sinaei *et al.* 2011, Aghaee and Foroughi 2013b, Aghaee and Foroughi 2013a, Aghaee and Yazdi 2014, Aghaee *et al.* 2014, Bala *et al.* 2014, Aghaee *et al.* 2015a, Aghaee *et al.* 2015b). The application of building information modeling technology as one of these tools has been employed in structure design and construction for survey commencing and realizing the building industry. The infrastructure projects are the key for supporting the social and economic development of every nation. Governments globally invest progressively in infrastructure projects for the country development. Many stakeholders presented in infrastructure projects, each having its own features, demands and targets (Andalib *et al.* 2010, Bazzaz 2010, Andalib 2011, Andalib *et al.* 2011, Bazzaz *et al.* 2011a, Bazzaz *et al.* 2011b, Bazzaz *et al.* 2012a, Bazzaz *et al.* 2012b, Porwal and Hewage 2013, Andalib *et al.* 2014, Bazzaz *et al.* 2014, Bazzaz *et al.* 2015a, Bazzaz *et al.* 2015b, Andalib *et al.* 2018). The benefits provided by BIM on a software tool play a supportive role during maintenance process. The research came to the conclusion that BIM as a useful program was established to support building inspections and future maintenance operation (Simões 2013). American national institute of technology and standard has estimated the loss caused by inconsistency among computer designs, engineering and software systems of building maintenance and implementation to be approximately 15.8 billion dollars, being the highest loss related to repair and maintenance phase (O'Connor *et al*. 2004). Therefore, structures protection must be considered thoroughly.

Moreover, building design, construction and implementation are time-consuming processes (Han and Golparvar-Fard 2017). In this regard, hospital buildings are not exception, and require knowledge, information and experts to achieve non-stop serving after implementation (Peng *et al*. 2017). Through investigations on construction information of the available hospitals, estimations indicate that approximately 10 to 12% of the construction price of hospital is spent annually on repair and maintenance cost of hospitals (Bugg and Collins 2017). Rundell (2006) recommended that owners can mitigate their cost portion by using building information from a BIM design process during the longer, more expensive maintenance and operation phase of lifecycle of the building, while Azhar *et al.* (2008) expressed that BIM let facility managers to enter the decision-making process in earlier stage, where the design and construction can be affected completely. Bortolini *et al*. (2017) investigated the potential benefits of data integration of Building Maintenance Management (BMM) in Building Information Modelling (BIM) in existing mechanisms. It is proved that BIM is an appropriate beneficial technology enabling storage and retrieval of integrated building, management and maintenance data for existing structures. Applying this method leaded to several advantages such as multiple reports generation, intelligence in the model, consistency in the data, integrated source of information and integrated views across all existing facility systems.

Regarding the fact that hospital is a vulnerable structure and must be protected during natural disasters, the building and facilities must be systematically investigated and in case of the existence of problem, must be repaired by proper price immediately. By the use of modern technologies, firms' efficiency has been promoted, progressing towards a better physical infrastructure development. At the end, in this study, using building information modeling in repairing and maintenance of Imam Khomeini Hospital's building has been identified.

2. BIM concept

Previously, architectures have usually been dependent on 2D technical maps including the plan, elevations and sections. While in modern design, BIM included, maps are provided in more than 3-D dimensions. In other words, the two dimensions of time and cost are accounted for not only the length, but also the depth and width aspects (Porwal and Hewage 2013, Sun *et al.* 2017). Building maintenance management is one of the consequential issues in construction management, and the primary purpose of repair and maintenance system is to provide a systematic procedure for controlling building status and existing facilities, optimizing its capabilities to reach the maximum efficiency and reducing their breakdown and disability rate. The systematic approach to repair and maintenance management was created since 1970 with computer systems (Costa 2013). BIM, as one of the modern tools, is a promising and new approach in the construction, engineering and architecture industry gaining a gradual popularity among contractors, engineers, architectures and owners as a creative procedure for creating, analyzing and managing building information data during its lifecycle. It has been provided (Ding *et al.* 2014). Overall, BIM adds 3-D modeling to the 2-D maps and its specifications, with specific features. It is stated that each represented design member in BIM, in addition to possessing its 3-D physical feature, is an array of exploratory studies information to conceptual design, first and second level studies, procurements, construction and setup, deployment, implementation period and even its finishing phase. Therefore, BIM can be summarized as the process of building information production and management during its lifecycle. In other words, a BIM model is a 3-D digital presentation of functional and physical features of a building (Kariuki 2014).

2.1 Using BIM in building industry

BIM is used in each phase of a construction project from

the very beginning to demolition. The application of 3-D states in design and construction can be taken into practice (Aaltonen and Kujala 2010). Modifications in various construction phases can easily be used in this model. Also, building facility paths like piping can be visually examined. In this model, all structure spaces are provided for builders regarding all details and a step up is taken to a better construction. Furthermore, applying this model paves the way to create proper connections among all the agents of a project. Providing time and price samples in this model helps significantly in project planning. In addition, space repair and maintenance management is one of the evident indices of this simulation (Eastman *et al.* 2011).

2.2 Application of BIM for construction management

In the common method of construction management, on the one hand, maps features and building are separately given. on the other hand, the executive maps of different design groups are separately but consistent provided with each other. Some of the problems of this method are inconsistency, full of mistakes and redoes that eventually lead to a reduction of work efficiency as well as increasing construction price (Costa 2013).

The primary difference between BIM model and a conventional 3-D CAD model saves the valuable information of the whole construction process along with all its components. These include cases such as the features, setup and assembly guide, production guarantee services, repair and maintenance constraints, components price information and so on (Ding *et al.* 2014). BIM is technically a CAD model connected to a databased, such that any information related to project can be saved in it. BIM, therefore, serves as a common source of information between the entire design team and building implementation. The result of this information integration is co-ordination increment, error and waste reduction and finally, increasing work efficiency (Foster 2012).

2.3 Timing schedule and repair and maintenance operations sequencing

Timing and planning of covering operations is one of the most important subjects of control process and construction management in protection process. These efforts continue during the repair-maintenance procedure, and it is continuously monitored throughout the phases so that the project is not deviated from the correct route. By adding timing schedule data to the 3-D BIM, a fourth dimension, named time, is added (Lagüela *et al*. 2014). This advantage has made BIM system a powerful tool for designing. This way, the fourth dimension of the model, which is, time, enables the project observers to visualize the project timing schedule, practically visualizing how effective the correct consequences of repair and maintenance is on the overall success of the project (Foster 2012). Overall, determining a timing schedule with BIM system causes the optimization of repair and maintenance operations consequences and project procurement management (Sheth *et al.* 2010).

2.4 Estimating repair and maintenance cost

One of the main properties of BIM is that every defined component has informationally related to the length, width and height and anything necessary for quantitative estimation of the project. Therefore, by extracting model materials and relating their quantitative information with financial estimation programs in a BIM system, it is possible to gain an accurate estimation of repair and maintenance process cost. In this system, the quantitative estimation and design of the project are dependent on each other, such that with the smallest change in design, its quantitative and financial impacts can easily be visible for all the project observers at the same time. Ultimately, with the help of BIM system, the possibility of investigating the getting ahead of the project from the cost of the project and eventually the bankruptcy of the project seems far from achieving (Sheth *et al*. 2010).

3. Research method

Fundamentally, the current status in the repair and maintenance part and building information modeling were investigated through a library study. After the completion of the initial studies, the available check lists in buildings were analyzed to evaluate the received information along with investigating the available standards and guidelines. In next steps, the manner of application and implementation were obtained in Revit software as a case study.

3.1 IFC[1] Support[2]

IFC Import and Interoperability with CAD Tools Solibri Model Checker can import building models from all products of major BIM software by using interface of the standardized IFC. International Foundation Classes (IFC) is an open, standardized way of saving digital building descriptions. IFC is expanded by Building SMART (earlier called IAI), and makes the effortless exchange of information between various BIM software products possible. Solibri Model Checker supports IFC versions IFC 1.5.1, IFC 2.0, IFC 2x, IFC 2x2, and IFC 2x3. Zip-compressed IFC files can imported without extracting them.

IFC Export Some BIM software products like the IFC export as part of the product, some others are available as separated modules. What follows is the list of BIM software with IFC export (https://www.solibri.com/bim-ifc).

4. A Review over causes of clashes and clash avoidance strategies

A systematic review of the drivers influencing soft and hard geometric clashes in a model of BIM and the clashes

[1] IFC (Industry Foundation Classes)
[2] https://www.solibri.com/bim-ifc

effects on achieving an efficient design have been summarized in Table below. Table 1 recommends that Designers working in isolation, design complexity, use of 2D instead of 3D models and design errors and etc. are all-important considerations when examining the primary causes of clashes.

Table 2 obviously shows that error-free models creation by designers is vital to achieve clash avoidance added recommendation that designers need much more "complete" design information (Akponeware and Adamu 2017).

5. Building information modeling in repairing and maintenance of hospital buildings

BIM provides a reliable basis for project technicians' group for decision made by conditions description of a building in reality during its lifecycle from the beginning to demolition. With the extension of this technology and addition of new dimensions, its application has been considered in building maintenance and implementation phases. The main question is, however, that whether the stored information in BIM software suffice to repair and maintenance phase in the current models or there is a need to add a new dimension regarding building maintenance and implementation issues and theories.

On this basis, the collected factors in library study and interviewing experts will be employed for the integration and standardization of an information database of repair and maintenance.

Table 1 The reasons of hard/soft clashes

Causes of Clashes
Use of wrong or low level of detail
Design uncertainty/use of Placeholders
Failing of design rules
Accuracy versus deadline
3D model objects exceeding allowable clearance
Designers working in isolation from each other
Design complexity
Insufficient time
Use of 2D instead of 3D models
Design errors
Use of different file formats
Lack of experts

Table 2 Clash avoidance and maintenance planning ways by researcher

Clash Avoidance Strategies
Impose BIM in traditional procurement
Integrating Engineering, Construction and Procurement
Improvement in software detection algorithms
Co-creation among designers in a shared workspace
Designers working with more information provided by other specialists
Designers being more careful/accurate with their own model output
Design coordination in a common data environment (CDE)
Shared situational awareness

Then, the possibility of adding these factors in the software are investigated and identified in details where this software can enter or the software for supporting the repairing and maintenance phase lacks them. One of the most time-consuming and costly parts in building maintenance and repair, is the initial identification and judgment along with providing the required information of the structure for optimal decision- making. Applying BIM, all the building information such as design, architecture, facility information, building infrastructures, structural information and so on, are provided for maintenance and implementation manager to make a decision for improvement, restoration or renovation of different parts of a building quickly and effectively.

The objectives of the present study

- Illustrating the relationship between hospital buildings' maintenance and repairing by the tool of building information modeling concept.
- Predicting the behavior of hospital construction based on ~~the~~ BIM in its maintenance and repairing
- Investigating the features of a standard and comprehensive database using BIM in hospital buildings' repair and maintenance

6. Results

Tehran Imam Khomeini Hospital, known as the thousand-bedroom hospital, is an educational hospital subordinate of Tehran University of Medical Sciences. It is one of the oldest Iranian Hospitals with a modern style, and is the biggest hospital in the Middle East with regard to treatment actions. It was built in 1934 on a ground of 25000 m^2 by German engineers. It was augmented with Valiasr Hospital complex in 1976.

Given the presented limitations, some repairing and maintenance experts were initially interviewed and a checklist was set. The interview included personal information, the process of identifying demolitions and the manner of decision-making for repairs and accessing maps and previous information, price financing, preventing methods and the application of repair and maintenance principles in the existing pump system.

Fig. 1 A view of Tehran Imam Khomeini Hospital

By receiving checklists associated with investigation of maintenance and repair standard of mechanical facilities of Iranian schools, section 22 of the national building regulations led to integrated tables and information to be recorded in BIM soft wares was provided.

Given that hardening is implemented throughout the year and its correct functioning causes an increase in efficiency and lifespan of other devices, controlling the hardness of the hard water outlet and ensuring that it is functioning correctly every two days is required as well as the performance of the necessary repairs and servicing. The hardness of the outlet water must be measured per visit and recorded in special notes. Whenever the hardness of water exceeds the allowed amount (50 PPM), hardening operation is performed.

Table 3 Some tips of the conducted interviews

NO	Interview tips
1	Map usage and correctness, updating of map information, providing a preventive system to avoid serious repairs, lack of using intelligent sensors, failing again caused by human error or incorrect recognition, keeping documents as paper, using checklist.
2	Application of subjective and schematic maps, not giving importance to map updates, lack of priority of case repairs, lack of using intelligent sensors, failing again caused by improper piece
3	Printed computer maps, continuous information updating, regular program of preventive repairs, prioritizing given the checklist, application for system warning and stop, failing again caused by human error, keeping documents as paper, using checklist
4	Printed computer maps, continuous information updating, regular program of preventive repairs, prioritizing given the checklist, application for system warning and stop, failing again caused by human error and improper pieces, keeping documents as paper, using checklist
5	Maps are required or case repairs are not prioritized with locating, providing and updating, lack of using intelligent sensors, failing again as a normal thing
6	Not using maps, lack of requirement, not prioritizing case repairs, using intelligent sensor, failing again caused by improper pieces
7	Case application, is updated in case of serious changes, case repairs, prioritizing based on application importance, using intelligent sensor, failing again caused by improper pieces, keeping documents as paper, using checklist

Fig. 2 A view of Imam Khomeini Hospital's facilities

Table 4 The applied checklists in repair and maintenance provided monthly in the hospital, scores the following

NO	Activity topic	Maximum score
1	Whether the hardness of water is regularly measured and, if necessary, a precise hardening procedure is performed	10
2	Whether the water hardness values are recorded per visit and after hardening according to the relevant checklist	10
3	Are all existing pumps intact and free of leaks and unusual sound, ready to operate or in orbit?	10
4	Is there a suitable tube to pump drain and water emptying into the chassis of the pumps, and the chassis and body of the pumps are without rust and sediment?	5
5	Are electrical pumps and their controlling and protecting devices visited, serviced and tested , and their consumption recorder and controlled?	10
6	Are underground and aerial water sources and associated facilities visited and serviced, and the internal side of sources are cleaned on determined time and required considerations for keeping their water healthy taken?	5
7	Are the workshop, facilities and other spaces in charge of the contractor being always cleaned?	10

All pumps in the engine room, pumping station, sewage treatment system and all parts of the facilities must be mechanically and electrically inspected and serviced. Filter, stabilizer, unilateral faucet, gauges and the relevant installed attachments must also be inspected and serviced, such that the system is always in orbit without any deficiency.

All pipes must be inspected regarding pipe corrosion and oldness and the safety of its insulation and must be repaired if necessary.

The sources under pressure must also be checked and serviced in certain times taking pipe burnout and aperture safety and the related pumps into account. Additionally, the related control devices must be visited and serviced in certain times.

Fire plumbing must be inspected regarding burnout and leakage and the related pumps and water system must be fully safe and ready to operate and the system must always be automatically in orbit.

6.1 Modeling results

The examined model is the engine room of internal heart part of Imam Khomeini Hospital, Tehran located in engine room pump facilities in ground floor. As the creation of a model for investigating the identified parameters of checklists and interviews tables is with objects parameters in the model, what follows is the model.

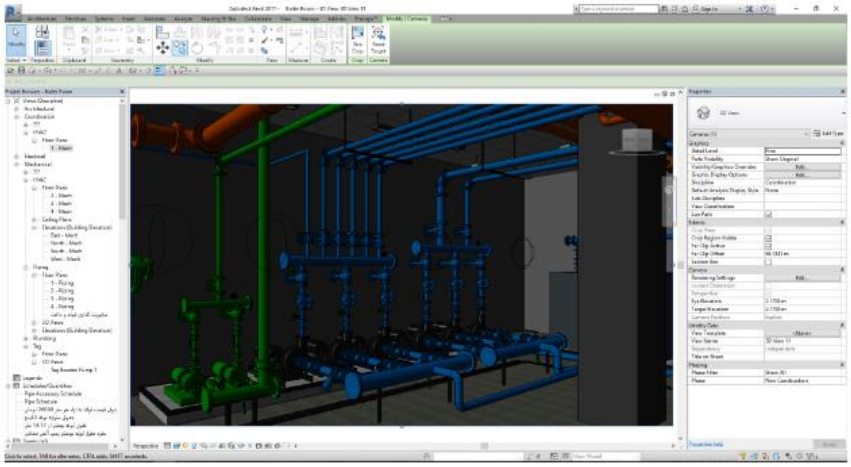

Fig. 3 Overall view of model

Fig. 4 Model facilities view

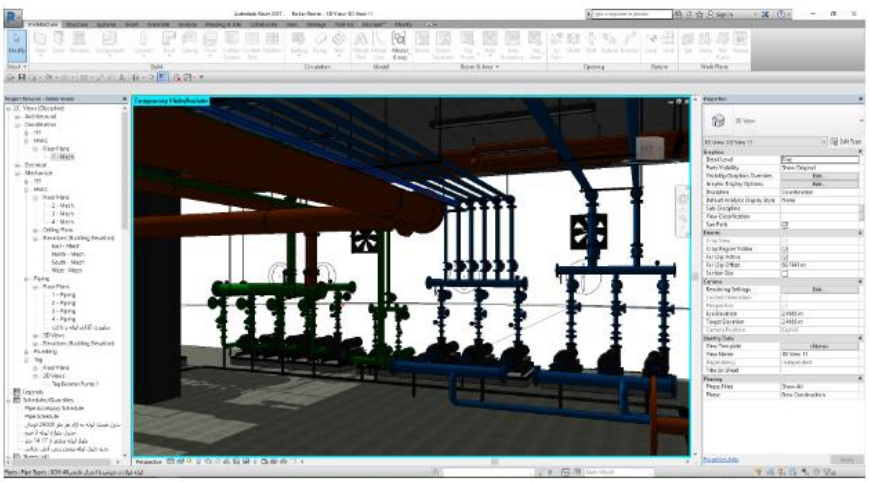

Fig. 5 Model facilities view

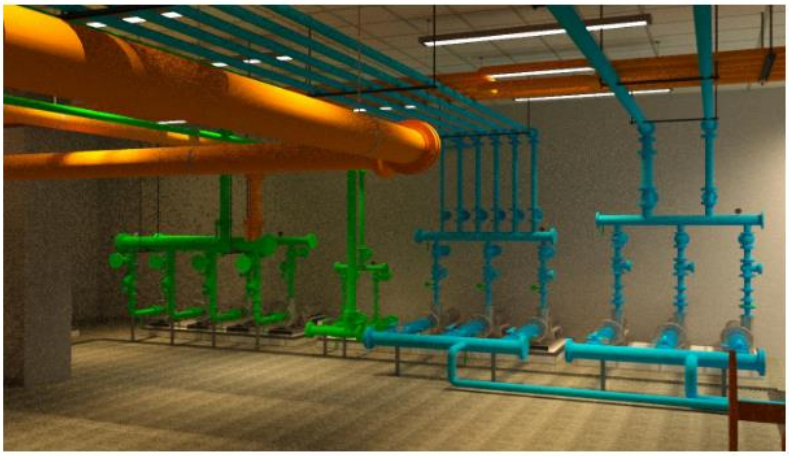

Fig. 6 Model facilities view

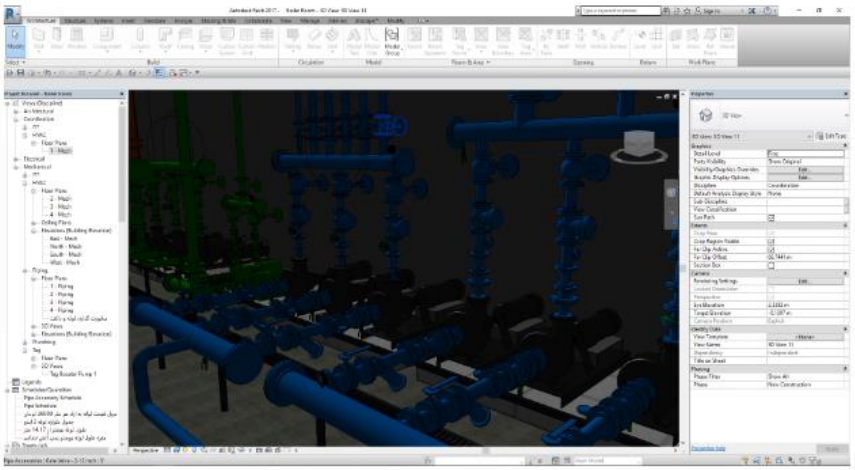

Fig. 7 Model facilities view

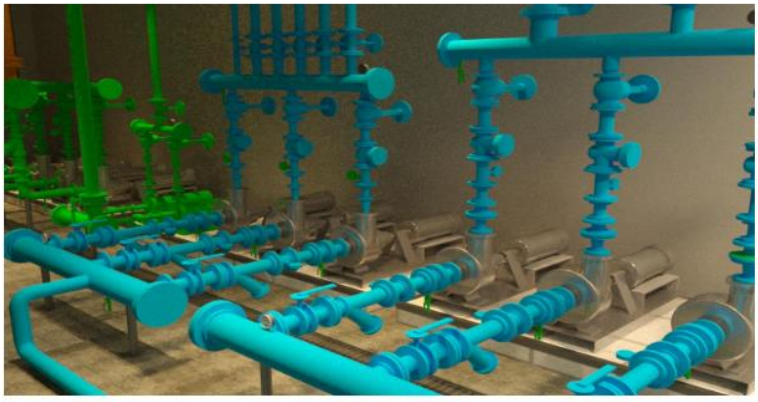

Fig. 8 Model facilities view

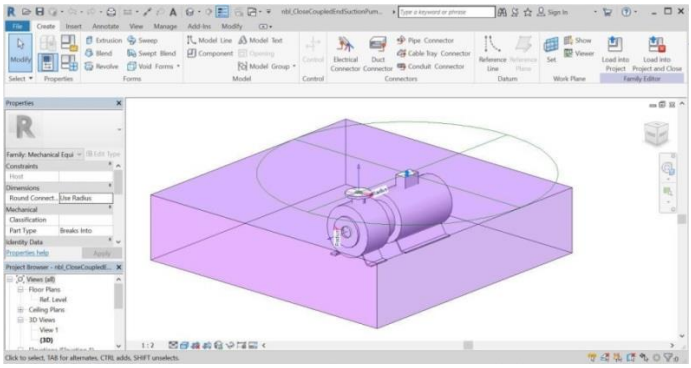

Fig. 9 Model facilities view

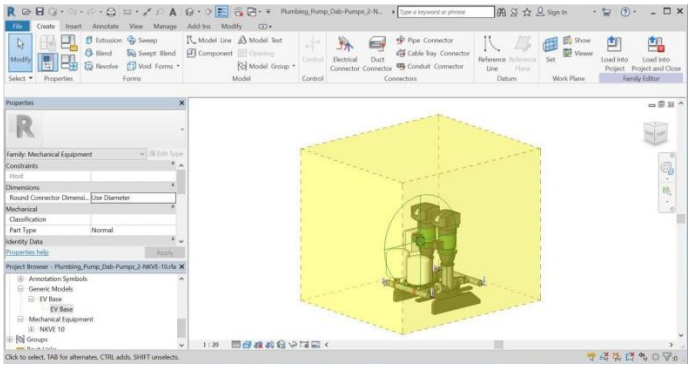

Fig. 10 Model facilities view

Table 3 The monthly evaluation and control of facilities maintenance and repairing

No	Evaluation indices	Desired score	Available score	Final score
1	Lubricating pumps and if necessary, bearings monthly		8	
2	Fiber and pumps spring statue		8	
3	Healthy coupling between engine and pump		8	
4	Input and output pressure statue of pump		8	
5	Standardization of the electric wiring current by the pump motor and the voltage applied to the pump		8	
6	On- time service of input pump line given break valve visit and unidirectional valve		8	
7	Stabilizer and metro meter not having deficiency in pump input line		8	
8	On- time service of pump input and output line given break valve and filter visit		8	
9	Stabilizer and monometer statue of output line		8	

Table 4 Following is an instance of difference between repairing and maintenance in case of using/ not using beam

Traditional note (net)	Note (net) using beam	Comparison table
12 times	7 times	Number of note (net) times annually
7000 $	12000 $	Note (net) price/cost

7. Conclusions

Today, BIM is applied as one of the novel devices in the design, construction and its management in the buildings. It is possible to convert the required information for maintenance and implement it into the descriptive and graphical information. In the descriptive section, such information as the price, guaranty, specific code, the amount of the functionality of the dependent mechanical and electrical parts, the dependent factory, the person responsible for visiting and visit date are specified. In the graphical part, some specifications such as dimensions, color, access and placement are considered by the implementer.

It can be inferred that with this study, a useful program was established to support construction inspections and maintenance operations in future would be accessible, which is associated with an architectural model in BIM, noted that the advantages would rise if the model of BIM integrates various specialties. One of the main benefits using BIM in building maintenance is to gain in productivity and a decrease in the error probability. Also, it

is concluded that BIM is an appropriate utile technology which enables storage and retrieval of integrated building, management and maintenance data for existing buildings. Using this approach yielded several benefits such as consistency in the data, intelligence in the model, integrated source of information and integrated views across all existing facility systems.

BIM, mostly used for construction management and design, has currently provided an opportunity to be used more during the lifecycle of the building, where, using this technology can cause an increase in lifespan of buildings with optimal operation and maintenance. Given the fact that one of the most costly and time- consuming parts of buildings repair and optimization is the initial identification and providing the required information of the existing structure for optimal decision- making, at this stage, if the given building information and structural components are not sufficiently available, performing repetitive visits of the structure and using non-destructive methods as well as many other experiments to determine the resistance of various building components will be inevitable. Therefore, the more fully and accurately the existing information of the building and its structural components are available, the required time and price for correct and optimal identification of how to repair the building will also significantly reduce. It is particularly considered a critical measurement at the occurrence of crisis. With regard to the received checklists of the interviewees, lack of a consistent management system and using traditional and paper practices, there is a shortage of the history of the repair and maintenance of the building under study. Hence, the need for a reliable and integrated database is totally felt.

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