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# Reducing rework and increasing the civil projects quality, through Total Quality Management (TQM), by using the concept of Building Information Modeling (BIM)

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**Abstract**

One of the important problems in the field of Construction Industry is 'rework'. It affects time, costs, quality, and almost every criteria of project success. As a result of rework and ineffective use of resources and materials in the workshops, there is always a considerable loss of resources, materials, investments, and workforce-time. Designing and planning through full awareness of clients and stakeholders, effective communication between the project factors, utilizing quality management systems, and using Information Technology [IT], can lead to a reduction of rework. In the recent years because of, the global development of IT, and widespread use of BIM-which coordinates all of the software and sections of the construction-the emergence of errors and inconsistencies have been dramatically decreased; helping the experts to realize their full professional potential in [doing] the projects. This study, while analyzing the effects of rework and its related factors on the civil projects, expresses the need for implementing TQM system through BIM tool, and finally provides a model for TQM implementation through using of BIM.

**Keywords:** Rework, rework factors and effects, Total Quality Management (TQM), Building Information Modeling (BIM)

## 1- Introduction

Hwang and others (2009) advise the managers to identify the most influential factors that lead to reworkings and their following effects, when planning for management of the project(Hwang, et al.,2009). According to studies conducted by Construction Industry Institute (CII, 2002), the errors in design and changes in the client orders, can be the results of: weak project definition, insufficient planning before the execution of the project, ineffective and inefficient design by the design team, weak communications (between clients, designers, and builders), or infeasibility of the designed plans. Therefore, attending to the mentioned points can lead to a reduction of rework.

An error management and a learning culture, in doing the projects, according to Love, can considerably reduce accidents and rework (up to more than 50 % as a result of ordering changes) (Love, et al.,2016). Moreover, various approaches such as BIM technology, Modular construction, Lean construction, assessing

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project feasibility by the design team, and project construction and procurement based on project team communications, can be effective in preventing rework(Love, et al, 2016).

In this study, by considering the factors and effects of rework, especially its direct effects on project quality, we will seek for ways to reduce such reworkings in order to achieve the desired/optimal quality in projects. To reach this goal, we will analyze the 7-fold principles of TQM in civil projects, and use the abilities that become accessible to us by understanding BIM, in order to overcome the challenges of implementing TQM. Finally, we will provide our suggested model for the implementation of TQM in civil projects, through the use of BIM approach. Figure 1 shows the process of the present study.

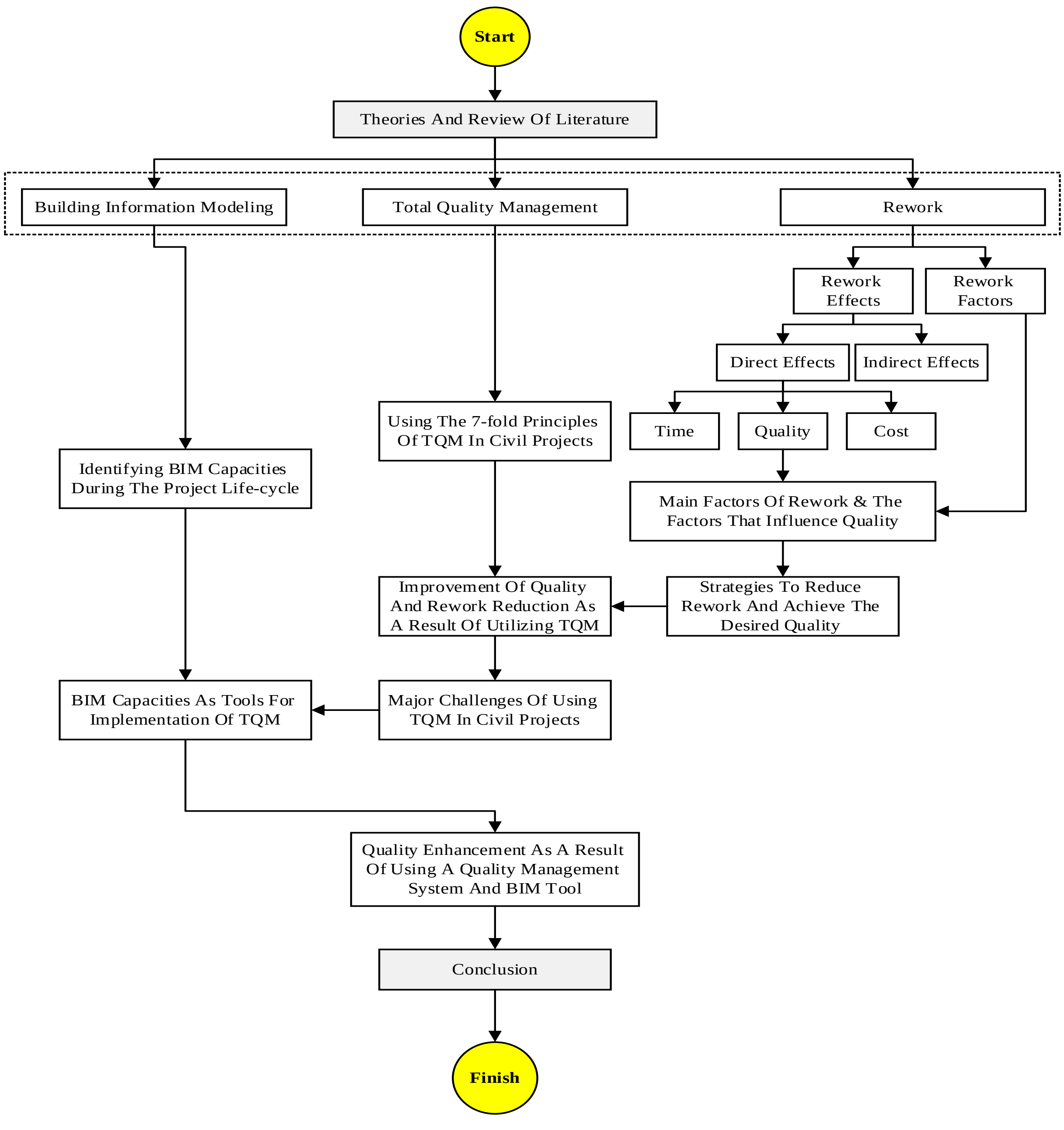


**Fig 1.** The research process

## 2- Theories and review of literature

Ashford defines rework as such: "Rework is the process by which an item is made to conform to the original requirements by completion or correction" (Ashford, 2002). Construction Industry Development Agency (CIDA) defines reworks as, "Doing a work/task (at least) more than once, for not conforming to or meeting the requirements." However, rework can mainly result from, errors, negligence, damages, and changes of orders that occur during the project (Love, et al., 1999). Love and others (1999) define rework as, "The unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time (Love, et al., 1999). Rework includes the following cases: errors in design and changes that influence construction activity, errors regarding constructability (or feasibility of construction), expanding or eliminating the scope of the project as a result of designers' or constructors' errors, and workers' botching tasks that affect the construction activities (Simpeh, 2012). Similarly, 'workshop rework', is defined as any activity that needs to be done more than once, or activities that as a part of the project eliminate the previously accomplished tasks. Good Manufacturing Practice institute defines rework as, "Production of a product that does not meet legal quality standards" (GMP, 2010). According to National House-Building Council defect is "The breach of any mandatory NHBC Requirement by the Builder or anyone employed by or acting for the Builder" (NHBC, 2011).

### 2-1- The Effects of Rework

Palanees Waran (2006), maintains that rework has direct and indirect effects on the project performance. For instance, in projects that have a weak management, the gross effect of rework (indirect and direct) equals or even exceeds the predicted benefit/profit. In some cases, it (rework) also affects various aspects such as stress, motivation, relations, and reputation (Palanees Waran, 2006). The direct effects of rework include waste of time as a result of rework, extra costs for covering the occurred rework, additional materials for doing the rework, controlling the subsequent waste, controlling the needed additional workforce for rework, and the addition of the supervision workforce (Simpeh, 2012). Rework can seriously affect an individual, an organization, and the project performance (Love, 2002). On the personal level, stress, exhaustion, absence, lack of motivation, and low morale, are some of the early indirect effects of rework. In fact, when an individual is faced with long working hours as a result of errors, changes, or negligence, exhaustion and stress arise, increasing the probability of rework emergence (Abdel-Hamind, Madnick, 1991). Love (2002) identifies the physiological and psychological effects of rework. For instance, increase in stress level as a result of additional costs and loss of profits, and obligation to repeat a task, can lead to demotivation (Love, 2002). A summary of the indirect effects of rework can be observed in figure 2.

According to Burati (1992), rework, especially in form of changes, can affect the aesthetic and functional aspects of the building. Rework has undesirable effects on the construction project performance within, cost, time, quality, and professional relation sections (Burati, et al., 1992). Fiddik maintains that lack of quality in construction manifests itself in: the inefficient way of working, insecure constructs, delays, cost increases, and conflicts in construction contracts. In (2010) Mastenbroek stated: Rework mostly means that some parts of the construct need to be demolished, and thus new materials are needed to rebuild them, which in turn leads to waste of resources (Mastenbroek, 2010). A summary of the direct effects of rework is displayed in figure 3.

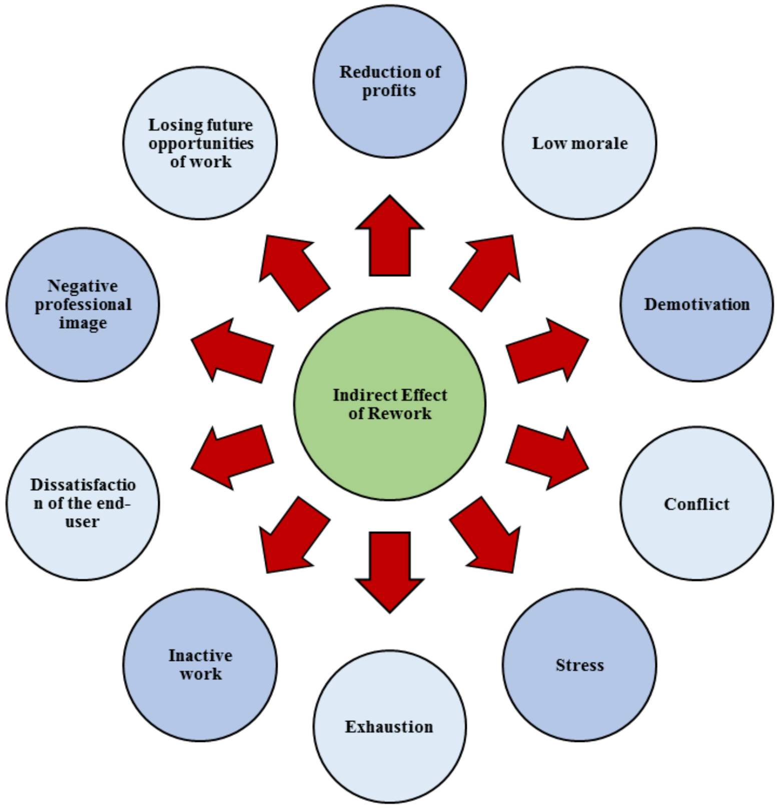


**Fig 2.** Indirect effects of rework

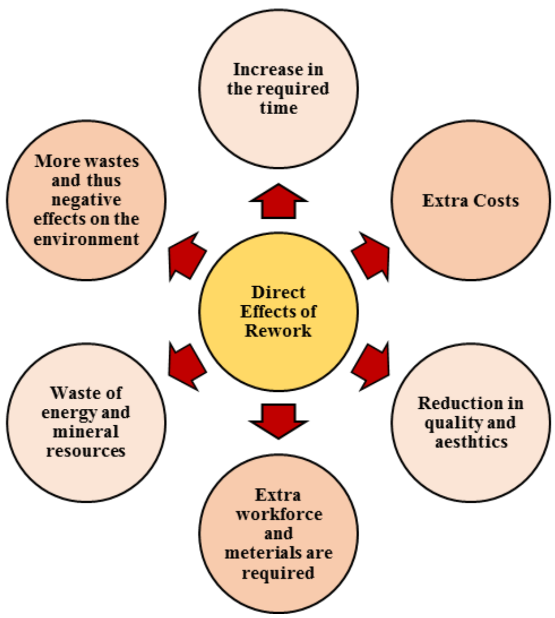


**Fig 3.** Direct effects of rework

## 2-2- Factors that influence rework

Rework may be expected in any construction project. Factors that influence the occurrence of rework include, nature of the project, procurement method, and complexity of the project (Simpeh, 2012). Palanees Waran (2006) demonstrated that compared to the civil projects, rework frequently happens in the building construction projects; and that, as a result of problems like lack of coordination between construction and facilities contractors, and weak communication between design and construction teams(Palanees Waran, 2006). The procurement method may influence the reworkings that may happen in a project. For instance, non-traditional methods have a higher rate of rework compared to the traditional ones; especially when, errors, negligence, and changes occur (Love, 2002). The type of the building is related to complexity and therefore, influences project performance (Naoum, Mustapha, 1994) (NEDO, 1988). Complexity is an item that encompasses two or more parts or variables (Ireland, 1985). To increase the quality, an understanding of the fundamental reasons of rework is required, and such an understanding can be achieved through simulation of the conditions that cause rework (Love, et al, 1999). Although rework is an accepted part of the construction process, yet the researches indicate, the uncertainty caused by weak information, as the main reason for rework. (Bowen, 1992) (Laufer, 1997). After studying the construction projects in Sweden, Josephson and others (2002) found out that wrong manner of working, improper or incomplete designing, lack of coordination between various disciplines, late delivery of materials, mistakes in planning, and defective construction, constitute the main reasons of rework(Josephson, et al., 2002). Having assessed 359 construction projects in CII database, Hwang and others (2009), concluded that changes made by clients, also errors and eliminations in design, are the most important reasons of rework (Hwang, et al., 2009). Love and others (2010) through analysis of 115 civil engineering projects, enumerated the main reasons for rework as such: ineffective use of IT, over-intervention of the client in the project, lack of clear work processes definitions, changes made at the request of the client, and inefficient changes made by the contractor to improve quality (Love, et al., 2010). Ye and others (2014) identified 47 reasons for rework, and through questionnaires and interviewing of 277 China construction industry professionals found out that unclear project processes management, low quality of construction technology, and use of low-quality materials, to be the most significant reasons of rework (Ye, et al., 2014). Dahanayake, Ramachandra identify the following, as factors involved in the emergence of defects: lack of supervision, undesirable working conditions, design errors, weak coordination of tasks between the project team members, weak materials, and weak way of working (Dahanayake, Ramachandra, 2016). The Alberta Construction Clients Council (2001) developed a fishbone categorizing system, to classify various reasons of rework. Figure (4) consists of five main categories of rework, and four subcategories under each category, explaining the probable reasons for rework. The following are the main categories: **1-** Human resources capability **2-** Leadership and communications **3-** Engineering and reviews **4-** Construction planning and scheduling **5-** Material and equipment.

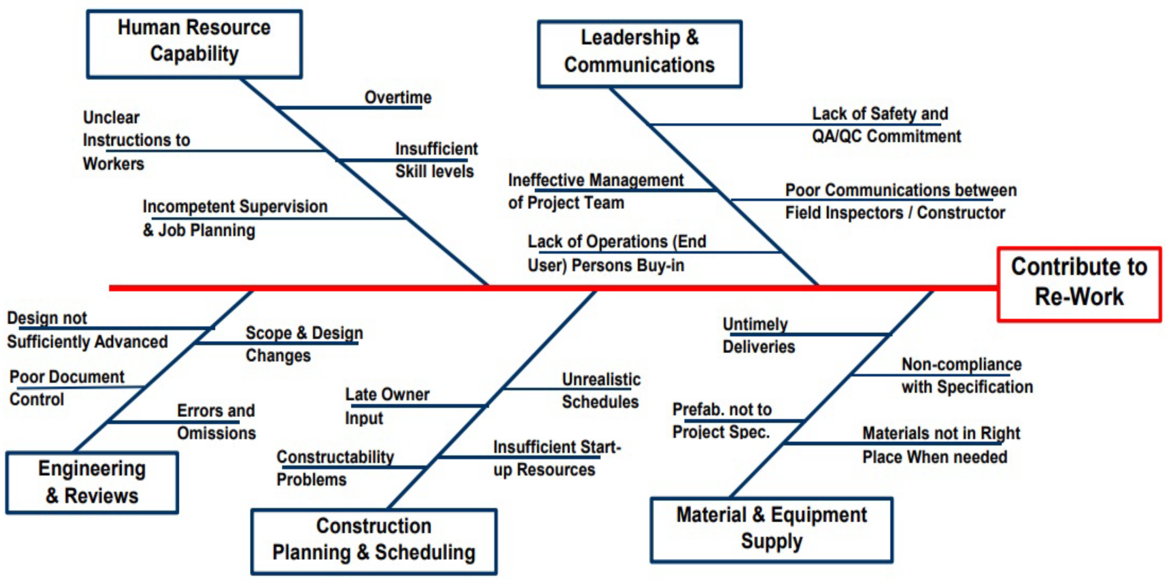


**Fig 4.** Reasons for rework (Fishbone chart)

To sum up the above-mentioned studies it can be concluded that various reasons with varying importance rates can cause rework. Table 1 shows 7 primary weaknesses that cause rework. Moreover, simple solutions that can be used as responses to these weaknesses are displayed on the right side of the table.

**Table 1.** Primary reasons of rework, and solutions to reduce their effect

| Primary Reasons for Rework | Solutions to Reduce Rework |
|---|---|
| A-Weak communications and conflict between project factors | Effective and comprehensive use of the workforce, and teamwork on all levels |
| B- Inefficient use of IT | Using new technologies of the project management field and constant improvement of work |
| C- Errors and Negligence, and clients' and stakeholders' inappropriate view of the project | Gaining the satisfaction of the client, and focusing on the workforce in order to reduce errors and negligence |
| D- Weak planning as a result of not assigning enough time to the planning and design processes | Assigning more time to the design process and more precision in calculations |
| E- Using low-quality materials and low-quality suppliers | Managing suppliers and treating them like stakeholders/partners |
| F- Workers not having the required abilities and lack of a skilled workforce | Training the human resources and using the experiences from previous projects |
| G- The insecure and inappropriate work environment | Project management's responsibility and support for meeting the standards of the project |

Love and Edward (2005) maintained that the total cost of rework is subject to direct and indirect costs (Love, Edwards, 2005). Moreover, according to Love (2002), the direct costs are easily measurable and are frequently stated in the assessment of the work method; they also show a considerable part of the total costs of the project. The rework costs include working hours, scheduling, equipment, materials, and space costs (Tommelein, et al., 2007). The indirect costs are not directly measurable and include, waste of time, reduction in productivity, legal claims and conflicts, and low-performance-efficiency (Love, 2002). Advising engineering companies and contractor companies need to establish a Quality Management System (QMS), a system which supports the quality costs. Organizations can understand the economic benefits of achieving high quality, only when they begin the precise measurement of the rework costs (Love, 2002).

Table (2) displays in components, the quality costs that the contractor companies need to undergo, in order to improve performance and reduce rework (Love, Irani, 2003) (Bowen, 1992).

**Table 2.**Quality costs

| | | | |
|---|---|---|---|
| Includes diagnosis of errors or defects through measuring accordance of the quality level with the required (quality) level | Evaluation | Control | **Quality Costs** |
| Includes the amount of made investments, to prevent or reduce the errors or defects | Prevention | | |
| Caused by rework, or a waste of defective products, or making up for delays in delivery | Internal | Control Failure | |
| Encompasses repair and return costs, dealing with complains, and compensations after delivery of the products to the client. | External | | |

According to Cusack (1992, projects that do not have a QMS, during the execution phase, as a result of rework, generally experience a 10% increase in costs ( Cusack, 1992). Love and Li (2000) concluded that when a contractor applies a QMS along with an effective [quality] improvement strategy, the rework costs decrease down to less than 1% of the contract value (Love, Li, 2000). Based on these findings and the previously mentioned points, the need for utilizing a system to control and guarantee quality, is emphasized more than ever. Regarding the fact that rework directly affects quality, and also the fact that the quality costs of a project(in case of not paying attention to quality)are high; thus, a TQM system is needed to eliminate the quality issues, and also to minimize the consequences of rework and quality costs, through promotion of the quality level.

## 2-3- Total Quality Management system

TQM is a method for management of an organization (project), to which quality and participation of all organization members (project team) are central. The goal of this system is the long-term accomplishment of success by satisfying the clients and supporting the stakeholders. ISO 9000 standards, developed by International Standard Organization (ISO), are widely used in construction and many other industries. Recently, this system has received an increasing attention in the construction industry (Turk, 2006). Consideration of the positive aspects of implementing TQM, and also the existing issues in the construction industry, have contributed to the mentality of using this system in the construction industry.

The existing issues in the construction industry that point towards the need for using TQM system are: **1-** Lack of records regarding results, experiences, and incidents in the civil projects **2-** Low quality of the civil projects execution **3-** Lack of attention regarding human resources and workplace necessities in the civil projects **4-** Lack of workgroups and the lack of workers' participation in the execution of civil operations **5-** Increase in the costs as a result of rework 6-Accidents and wastes in construction works (Ghodoosi, Bidi, 2011).

In order to overcome these obstacles, a profound understanding of the seven primary concepts of TQM is necessary. These concepts are: **1-** A project management that is committed to application TQM on all fields' **2-** Constant attention to internal customers (project team members) and external customers (clients), and gaining the satisfaction of all the project stakeholders **3-** Efficient and inclusive use of workforce and application of teamwork on all levels **4-** Continuous improvement of work and project construction processes **5-** Treating suppliers as partners **6-** Securing and controlling quality (Pike, Barnes, 1995). Having the required commitment and conviction in innovation and continuous improvement, having the required knowledge in the fields of tools and techniques needed for change, and participation of all employees and workers in bringing change, form the foundations of TQM culture. If the works/tasks are done right in the very first attempt, there will be almost no wastes, the costs will be minimal, and the benefits maximal (Chini, Valdes, 2003). TQM is the improvement of the traditional ways of doing works and using the established technical experiences, that guarantee survival in the competitive world of the present time (Pike, Barness, 1995). Figure 5 demonstrates the generally accepted elements of TQM that are effective on the quality of the processes of a construction project (Arditi, Gunaydin, 1997).

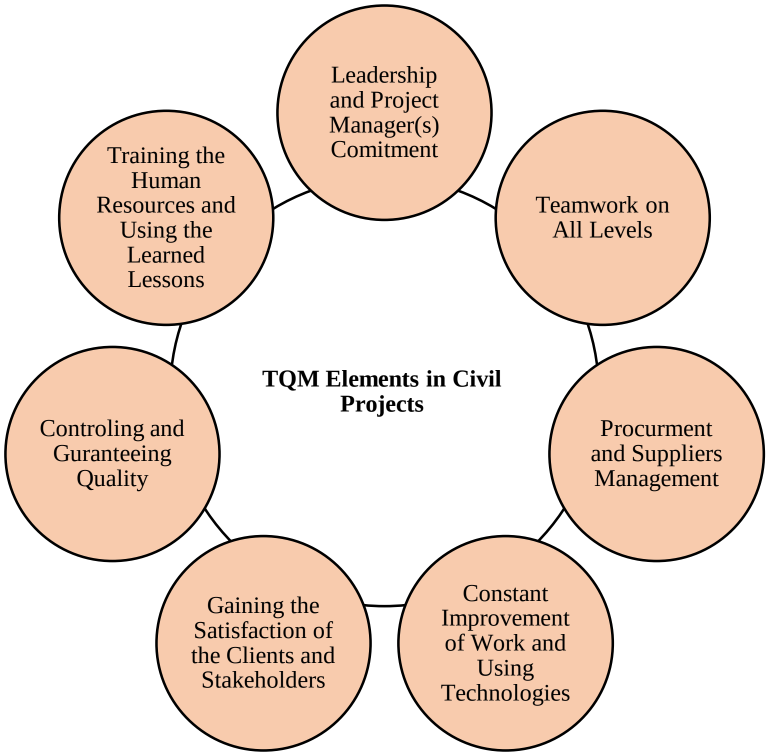


**Fig 5.** TQM elements in civil projects

The points mentioned in figure 5 are the solutions to reduce reworks in table 1. That is to say [once again] TQM is necessary to reduce rework and to achieve the desired quality. Table 3 provides the ways to reduce rework through the elements of TQM.

**Table 3.** Elements of rework reduction through TQM

| The Causes of Rework | Solutions to Reduce Rework | TQM Elements |
|---|---|---|
| **A-**Weak communications and conflict between project factors | Effective and comprehensive use of the workforce, and teamwork on all levels | Teamwork across all levels of the project |
| **B-** Inefficient use of IT | Using new technologies of the project management field and constant improvement of work | Constant improvement of work and the use of technologies |
| **C-** Errors and Negligence, and clients' and stakeholders' inappropriate view of the project | Gaining the satisfaction of the client, and focusing on the workforce in order to reduce errors and negligence | Gaining the satisfaction of the clients and stakeholders |
| **D-** Weak planning as a result of not assigning enough time to the planning and design processes | Assigning more time to the design process and more precision in calculations | Assigning more time for developing a quality guarantee system |
| **E-** Using low-quality materials and low-quality suppliers | Managing suppliers and treating them like stakeholders/partners | Procurement and suppliers management |
| **F-** Workers not having the required abilities and lack of a skilled workforce | Training the human resources and using the experiences from previous projects | Training the human resources and using the learnings |
| **G-** The insecure and inappropriate work environment | Project management's responsibility and support for meeting the standards of the project | Leadership and project manager(s) commitment |

Although there are benefits in using TQM system, like any other system that is going to be implemented within the organization, there are also challenges in its implementation and in gaining its full benefits, the most significant of which follows as such:

1. The unwillingness of many workers/employees to participate, while the participation of all workforce on all levels is required.
2. Management's resistance to workforce empowerment; based on the belief that more workforce participation in decision making will reduce the management's role
3. Independence crisis; that is to say each unit may consider themselves as a separate part that has no relation to other section and regards the cooperation of others unnecessary.
4. The traditional workforce is not willing and interested to involve statistics and numeral data in their work.
5. The formation of the belief that the establishment of a quality management system is only paperwork, leading to increased waste of time without any results.
6. The workforce may believe that their present products are high-quality, and there is no need to be concerned with the quality.

Two essential factors preventing the establishment of TQM in projects are: 1-The lack of good communications among the project team and the stakeholders and 2-The lenient role of new technologies in projects. In other words, by accomplishing these two points such challenges can be desirably reduced, and TQM can be used more beneficially.

As it was observed, the establishment of a TQM system leads to increase in the quality and to a reduction in rework. Since the TQM is rather a concept and a guiding principle, there is a need for tools to implement the concepts related to it, in order to: first, constantly improve project tasks [quality] and gain access to new technologies; and second, to increase communication between various sections of the project.

## 2-4- Building information modeling

During the early 1960s, the construction industry faced a gradual reduction in productivity of the human resources. Meanwhile, other industries were enjoying an enhanced productivity of the human resources (Rooke, et al., 2004). Island-like nature of the construction industry due to its approach to contracts, its use of 2D drawing methods (CAD Software), and the size and magnitude of the construction companies can be regarded as the main reasons for a low productivity indicator (Teicholz, 2004). Here, the inefficiency of 2D design methods in accomplishing an effective communication with the stakeholders can be pointed to as a significant factor. In a situation where each of the factors involved in the 2D plans corresponded to its related discipline, the plans that lacked the capacity to integrate and adapt to other plans, led to information conflicts and therefore a reduction in the workforce productivity (Teicholz, 2004). On the other hand, 2D designs lacked the capacity to integrate with and encompass the costs and planning information. Moreover, the downward flow of construction workforce payments had led to lack of pressure for an increase in workers productivity. Thus, any attempts to come up with new methods was not economically justified (Teicholz, 2004). In 1997 a new revolution introduced a 3D design tool that used a shared data source. Such a shared data source made the changes in designs-at any point of the designs-possible and automatically applied the changes to other design documents. The database could also be shared between large numbers of users. Architecture, structure, and facility models could be made as linked and merged together (Migilinskas, et al., 2013). According to Eastman, BIM is more than a software, it is a human activity that transforms design, construction, and construction management processes (Eastman, et al., 2011). General Services Administration (GSA) defines BIM as: "Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which, views appropriate to various users' needs can be extracted and analyzed to generate feedback and improvement of the facility design"(Parvan, 2012). BIM has the capacity to bring together all the required information during the project lifecycle including, spatial relations, geographical position, quantity and specifications of building parts, cost estimation, list of materials, and the project schedule. The integrity of the information extracted from the design process, and its consequent coordination of information, make BIM stand out in comparison with the CAD-based design methods. In order to have a better understanding, CAD data can be compared to detached islands, while BIM data can be associated with connected and unified ones. Table 4 expresses a set of BIM capacities during the project life cycle.

**Table 4.** BIM capabilities during the project life cycle

| BIM Capacities and Functions | | |
|---|---|---|
| **1** | **Parametric members** | Parametric data are the data that differentiate one part from other similar parts. For instance, although all of the walls are designed through a tool menu, they are also made of unique parameters, such as dimensions, materials, or a specific supplying company, which differentiate them from other walls. In addition, the intelligence of the parts in modeling is not limited to them, they are also assessable in relation to the rest of the parts (Eastman, et al., 2011). |
| **2** | **3D Model, Increased Vision Precision, and Reduction of Claims** | The complexity of work, length of the execution phase, and different interpretations of the project by the contract parties are the bed form which claims rise. Contract parties having access to a 3D model of the project before the execution, negates all the cases of various interpretations, work complexity, and extra time. That is to say, an appropriate project management reduces the rise of claims (Eastman, et al, 2011). |
| **3** | **Integrated Change Management** | The users can have access to any required 2D designs through BIM model (horizontal, vertical …cuts). In case of changes to any of the parts, the change applies to any other dependent part(s) as a result of (the parts) being parametric (Winberg, A., 2010). |
| **4** | **Fabrication** | Because of the availability of all required constituent parts and sections, BIM, makes pre-construction (out of the construction site) possible (Winberg, A., 2010). |

**Table 4.** Continued

| BIM Capacities and Functions | | |
|---|---|---|
| 5 | **Documentation** | At the end of the project, the project manager can present a comprehensive model of building information to the client. A model which includes information such as: links to approvals, maintenance and utilizing information, warranties, guarantees, security and safety information (such as lighting information and firefighting system, alarm, and smoke sensors); in addition the facilities management team, based on the information given to the client, can execute energy analysis and optimization systems during the facilities utilizing time period (Hergunsel, M. F., 2011). |
| 6 | **Construction Process Simulation, and Saving Time during the Project Execution** | A 4D model can be gained by integration of graphic images with the time dimension. In 3D modeling, a graphic model of 3 spatial dimensions is connected to the time dimension, so the order and sequences of different project steps are shown in real-time. 4D modeling tool enables the project planner to plan activities with respect to time and space dimensions. This makes, the coordination of execution methods with the [construction] site conditions, placement of crane tower, burrowing details, and such activities, possible. The studies show that 4D models indicate the design conflicts before the execution phase, and reduce the spatial-temporal conflicts and eliminate their ensuing rework (Eastman, et al, 2011). |
| 7 | **5D Model, and Precise Quantity Surveying and Cost Estimation** | A 5D model of building information requires integration of the 3D model with time and cost aspects of the project. This makes the anticipation and tracing of the project costs during any of the various phases possible (Dang, D.T.P., 2012). In this system, the extraction of the work amounts and the required materials, also other dimension details, from the 3D model, are very easy (Hergunsel, M. F., 2011). |
| 8 | **Equipment Management** | The equipment management groups can utilize BIM for renovation, spatial planning, and building maintenance (Eastman, et al, 2011). |
| 9 | **Facility Management** | One of the most important functions of BIM in the management of the facilities is the collection and record of the needed data on the parts and equipment used in the building, to be referred to during the utilization period. The data regarding performance inspection, warranty period, equipment and materials features, etc. can play a problem-solving role in the maintenance process (Akula, M, 2013). |
| 10 | **Sustainable Design and Construction** | The smart data made through BIM, have the capacity to assess total building energy, simulate its (energy) performance, selecting the best approach/orientation to it, internal lighting analysis, and the presentation of such assessments (Krygiel, E., Nies, B., 2008). |
| 11 | **Constructability** | An established capacity of BIM is the coordination of the various groups of design (Architecture, construction, and facilities), and therefore maximal adaptation of design and construction processes. This has a meaningful effect on reducing the costs and time of the project. |
| 12 | **Enhancing Safety** | BIM is known as a tool for improving the safety and health of the workforce. BIM can be used for, training the workforce, safety-based design of the construction site, safety planning (analyzing workplace dangers,), identifying and analyzing the risk management factors, determining the excavation equipment scope of motion, determining the storage place of materials and pre-made parts, and determining the security and safety measures during the utilization and maintenance phases. Through making a shared 3D model of the buildings for the groups involved in design and construction, BIM reduces the risks during the construction (Khoshnava, R., 2010).. |
| 13 | **Conflict Detection** | Since the virtual 3D model of the building is the source of all 2D and 3D plans, the design errors resulting from the 2D plans are eliminated. Conflicts and constructability problems are identified before happening in the site. Coordination between designers and contractors rises, and negligence is significantly reduced. This capacity accelerates the construction process, reduces costs, minimizes the probability of legal conflicts, and brings about an easier construction process for the project team (Eastman, et al, 2011). |

**Table 4.** Continued

| | BIM Capacities and Functions | |
|---|---|---|
| 14 | **Cooperation between the Project Team** | The design and construction of a building are group and team activities. Naturally working with various models is more difficult and time-consuming, compared to working with an integrated 3D model. In such a 3D model, change control can be managed better, while cooperation through drawings is also possible. This reduces the design time and minimizes the mistakes and errors of the design process. It provides new insights regarding the design problems and also provides opportunities for the constant improvement of the design (Eastman, et al, 2011). |
| 15 | **Improving Communication, and Reinforcing Cooperation and Coordination** | By using BIM, anyone can see their task in relation to others. On a data exchange level, the building model, because of high readability, supports the automatic translation of BIM and accessibility of the design information for anyone-throughout the design and construction processes (Eastman, et al, 2011). |
| 16 | **Quick Response to Changes in the Design** | The changes in the proposed design can impact the construction model, and automatically apply the changes on the other objects. The updates are done automatically and are based on rational parametric laws. Moreover, the changes in design can be applied faster through BIM, that is because the corrections can be shared, analyzed, and applied without the time consuming paper-based processes (Eastman, et al, 2011). |

Figure 6 shows the capabilities of BIM during the project life cycle.

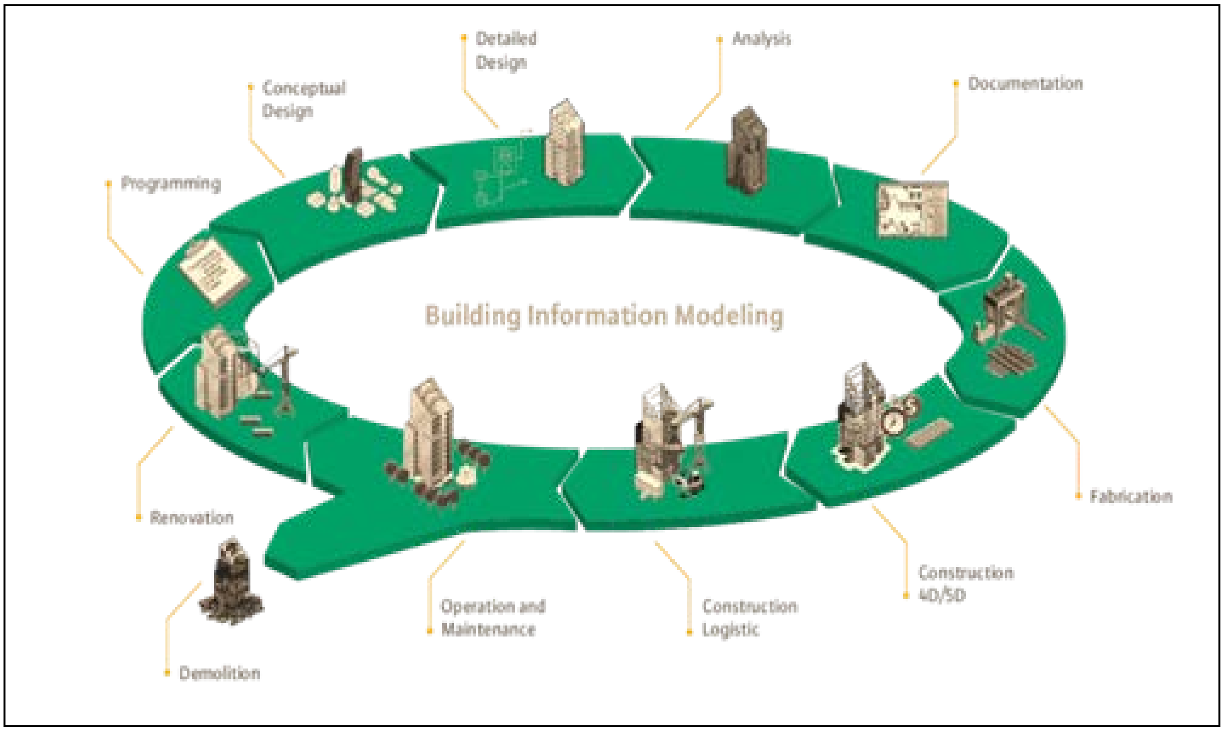


**Fig 6.** The capabilities of BIM during the project life-cycle

## 2-5- Analyzing the articles and investigating the research gap

The articles have been reviewed in three sections: reworking, Total Quality Management, and Building Information Modeling. Analysis of these articles is as follows:

1) According to the articles in the reworking section, only the factors and effects of reworking on the success of the project, especially the quality of the project, have been examined. By summarizing the articles, we arrived at the seven major factors, and with considering that reworking have direct effects on quality, as well as cost of quality in a project, we need a total quality management system in projects. We have to eliminate the problems in quality and by improving the quality level guaranteed in the project, we will minimize the consequences of reworking and we get quality and reduce costs (so we have tried to introduce a total quality management in the projects)
2) In the field of total quality management, few articles have been devoted to the implementation of TQM in the projects, and only one concept and theory for implementation of TQM reduction of reworking are expressed. Given that one of the most important features of the projects is the uncertainty due to the uniqueness of the projects (such as uncertainty based on project estimates, uncertainty in design and logistics, Uncertainty in the relationship between project partners), we need a tool that can reduce these uncertainties to reduce reworking. Regarding the review of past papers, first, the issue of TQM in projects to reduce reworking has been mostly ignored and it remained as a concept, secondly, a practical approach to implement the total quality management in projects such as how to collaborate between project elements and the use of new technologies have not been presented due to uncertainties. Due to lack of studies on how to implement of TQM in projects, as well as considering the problems for this implementation, the need to an efficient tool is felt to reduce uncertainties in project, implement TQM in projects and in order to eliminate the reworking and its effects.
3) The Building Information Modeling (BIM) is an efficient tool for integrating all the information in the life cycle of project and simulating the process of building the project and it could be an efficient tool for the above-mentioned necessities. By reviewing the articles in this field, the topic of application of building information modeling to reduce reworking in the project and reducing its costs and how to reduce these reworking have not been addressed and that it is possible to look at BIM as a tool for implementing some of the elements of total quality management in projects.

In summary, the goal of introducing building information modeling as a useful methodology is for implementation of total quality management in projects and reducing uncertainties in projects to provide practical guidelines for reducing reworking, reducing costs and its impacts.

## 3- The role of BIM in rework reduction and quality enhancement according to TQM, and the suggested model for implementation of BIM in civil projects

Regarding the multiplicity of the construction project operators (including, designers, calculators, facilities technicians, utilizers, expert managers, and investors), and the fact that each of these agents have their unique point of view and motivations, and also the fact that from a certain point of view all of them have a share in the project benefits; there is a need for coming up with a shared aspect in order to optimize the construction process. Considering the worldwide studies conducted on this field, it has become clear the most important factor (the shared aspect) is: the establishment of effective communication and cooperation between various sections/parts of the project. The first manifestation of such cooperation and communication is the reduction in the time needed for the exchange of documents and plans, and the enhancement of accuracy in these documents; that is because it reduces the communication time and errors. Whether in the design, construction, or utilization phases, cooperation and coordination lead to savings in time and costs and paying attention to the related considerations. Therefore, all sections can reach a beneficial shared aspect for their and others good, and also avoid errors of data exchange in or between various phases. BIM is a technology that simulates the design, execution, and utilization processes of a building in a virtual environment, and through such means, provides an accurate and comprehensive model of the building. A BIM information model is, in fact, a rich and intelligent database, a parametric digital representation of the building that the information and data of which can be accessed and analyzed at any given time by any user, and therefore, promote the possibility of appropriate decision making about the construction/building. The main goal of using BIM is the making of a virtual model of the building before the construction of the real physical one; so that the problems and issues can be observed and eliminated, and that the real building can be constructed with fewer defects, reduced costs, within a shorter time period, and with high quality. Actually, all of the information related to the various stages and phases of design or construction merge together through BIM, and form an electronic ID for the building that can promote the conditions and features of the building and its infrastructures; it can also be used as the most credible and referable information source regarding the building and its various sections.

## 3-1- Measure the impact and effect of rework factors through Dematel

Dematel technique is based on a pair of comparisons of decision making methods, applying experts' views in exploiting factors of a system and structuring them systematically using principles of graph theory, lead us to a hierarchical structure consisted of factors of the system along with the impact and effect relations which are displayed in forms of numbers.

### 3-1-1- The steps of the Dematel technique to measure the impact and effect of rework factors

**Step 1: Generate direct relation matrix (M)**

We obtain the effect of each factor of rework through binary comparison and using oral views and questionnaires. Afterward, we convert them into numbers. Considering that questionnaires are filled by some experts, we calculate the arithmetic mean of the numerical values. Mean values are shown in table 5.

| **Preference (verbal judgment)** | Very high influence | High influence | Low influence | Very low influence | No influence |
|---|---|---|---|---|---|
| **numerical value** | 4 | 3 | 2 | 1 | 0 |

**Table 5.** Matrix M

| | M | | | | | | | Sum |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | |
| A | 0 | 0.75 | 3.25 | 3.25 | 2.25 | 1.75 | 1.25 | 12.5 |
| B | 2.5 | 0 | 3 | 3 | 1.5 | 1.75 | 1.25 | 13 |
| C | 2.25 | 1.25 | 0 | 2.5 | 2 | 2 | 2 | 12 |
| D | 3.5 | 2.25 | 3.5 | 0 | 2.25 | 2 | 2.75 | 16.25 |
| E | 1.75 | 1 | 1 | 1.25 | 0 | 1.25 | 2.25 | 8.5 |
| F | 2.5 | 2.25 | 2.5 | 2.5 | 1.5 | 0 | 3 | 14.25 |
| G | 1.25 | 0.75 | 2 | 1.75 | 2 | 2 | 0 | 9.75 |
| K | | | | | | | | 0.061538 |

**Step 2: Normalize the direct relation matrix and form matrix (N)**

First, calculate the sum of each row to obtain a column vector, then find the maximum element of the mentioned vector and consider its reverse as k (according to formula 1). the product of number k and matrix M is matrix N (according to formula 2).

$$K = \frac{1}{max \sum_{j=1}^{n} a_{ij}} \quad (1)$$

$$N = K \times M \tag{2}$$

**Table 6.** matrix N

| | N | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| A | 0 | 0.04615 | 0.2 | 0.2 | 0.13846 | 0.10769 | 0.07692 |
| B | 0.15385 | 0 | 0.18462 | 0.18462 | 0.09231 | 0.10769 | 0.07692 |
| C | 0.13846 | 0.07692 | 0 | 0.15385 | 0.12308 | 0.12308 | 0.12308 |
| D | 0.21538 | 0.13846 | 0.21538 | 0 | 0.13846 | 0.12308 | 0.16923 |
| E | 0.10769 | 0.06154 | 0.06154 | 0.07692 | 0 | 0.07692 | 0.13846 |
| F | 0.15385 | 0.13846 | 0.15385 | 0.15385 | 0.09231 | 0 | 0.18462 |
| G | 0.07692 | 0.04615 | 0.12308 | 0.10769 | 0.12308 | 0.12308 | 0 |

**Step 3: Generate complete relation matrix (T)**

This matrix will be derived from the formula (3):

$$\mathrm{T} = \mathrm{N} \times (\mathrm{I} - \mathrm{N})^{-1} \tag{3}$$

**Step 4: Generate the Matrix Threshold Value (T)**

This value is equal to the total average of the T-matrix strings (formula (4)):

$$\text{Treshhold} = \text{Average}(\mathrm{T}_{ij}) \tag{4}$$

**Table 7.** matrix T

| | T=N×(I-N)$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| A | 0.40568 | 0.30018 | 0.61042 | 0.57982 | 0.47176 | 0.42158 | 0.44762 |
| B | 0.56089 | 0.26604 | 0.62585 | 0.59403 | 0.45107 | 0.43838 | 0.46148 |
| C | 0.50619 | 0.31234 | 0.4213 | 0.52626 | 0.44272 | 0.41921 | 0.46564 |
| D | 0.67714 | 0.4293 | 0.7273 | 0.51265 | 0.55361 | 0.51148 | 0.60169 |
| E | 0.36728 | 0.22709 | 0.35828 | 0.35107 | 0.23764 | 0.29262 | 0.37462 |
| F | 0.58113 | 0.40151 | 0.62734 | 0.59435 | 0.47304 | 0.36278 | 0.57047 |
| G | 0.38597 | 0.24356 | 0.4504 | 0.41605 | 0.38176 | 0.36308 | 0.29416 |
| (T) | **0.450935248** | | | | | | |

**Step 5: Draw a cause and effect chart**

To do this, we rewrite the matrix T as follows:

If element Tij is equal or bigger than the threshold of matrix T, the value of the foresaid element becomes 1, otherwise it becomes 0. Hence, the matrix S is obtained.

Impact and effect network is illustrated in figure 7.

**Table 8.** matrix N

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| B | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| C | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| D | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| E | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

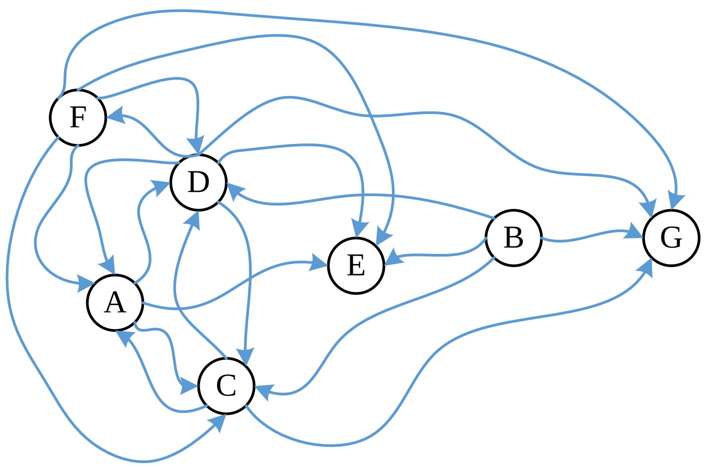


**Fig 7.** The impact and effect network of rework factors

**Step 6: Analysis**

The sum of the elements of each row (D) for each factor indicates its effect on other system factors. (Effect of variables). The sum of the elements of the each column (R) for each factor indicates its impact on other system factors (impact of the variables - table 9).

Finally, we have a Cartesian coordinate system. In the system, the axis of length is measured by D+R and the axis of width is measured by D-R.

The position of each factor in the system is determined by a point with the coordinate of (D+R, D-R). therefore, we have a graphical diagram, too. Hence, the horizontal vector D+R indicates the impact and effect of the factor in the system. In another words, the higher D+R of a factor is, the more interactive the factor is and the vector D-R indicated how effective a factor is (figure 8).

**Table 9.** Analysis matrix T

| | T=N×(I-N) $^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| A | 0.40568 | 0.30018 | 0.61042 | 0.57982 | 0.47176 | 0.42158 | 0.44762 |
| B | 0.56089 | 0.26604 | 0.62585 | 0.59403 | 0.45107 | 0.43838 | 0.46148 |
| C | 0.50619 | 0.31234 | 0.4213 | 0.52626 | 0.44272 | 0.41921 | 0.46564 |
| D | 0.67714 | 0.4293 | 0.7273 | 0.51265 | 0.55361 | 0.51148 | 0.60169 |
| E | 0.36728 | 0.22709 | 0.35828 | 0.35107 | 0.23764 | 0.29262 | 0.37462 |
| F | 0.58113 | 0.40151 | 0.62734 | 0.59435 | 0.47304 | 0.36278 | 0.57047 |
| G | 0.38597 | 0.24356 | 0.4504 | 0.41605 | 0.38176 | 0.36308 | 0.29416 |
| (T) | **0.450935248** | | | | | | |
| R | 3.48428 | 2.18002 | 3.82089 | 3.57421 | 3.0116 | 2.80914 | 3.21568 |
| D | 3.23706 | 3.39774 | 3.09365 | 4.01318 | 2.2086 | 3.61061 | 2.53498 |
| R+D | 6.72134 | 5.57776 | 6.91455 | 7.5874 | 5.2202 | 6.41976 | 5.75066 |
| R-D | -0.2472 | 1.21773 | -0.7272 | 0.43897 | -0.803 | 0.80147 | -0.6807 |

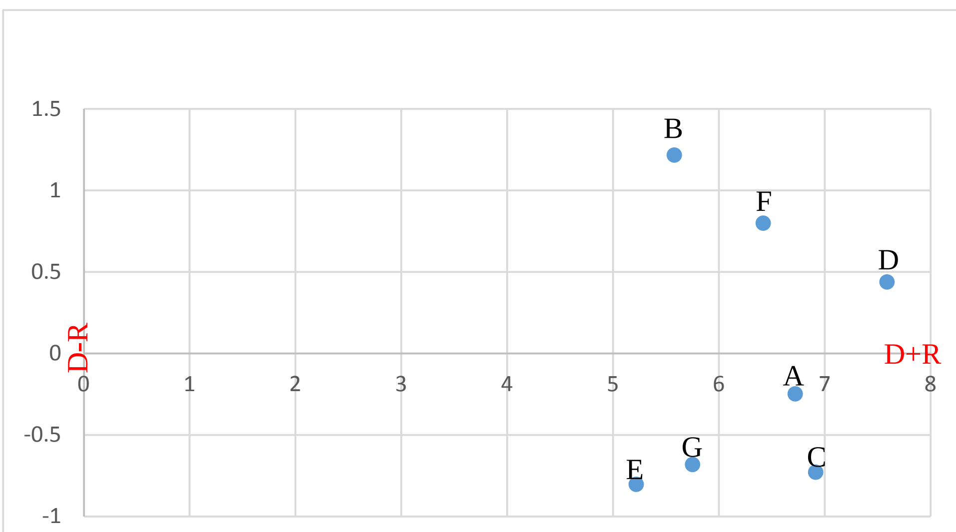


**Fig 8.** impact and effect chart of rework factors

Therefore, the most duplication influential factor is D- Weak planning as a result of not assigning enough time to the planning and design processes . Regarding building data modeling approach: the design and planning phase requires the most of the time and attention in order to avoid possible rework difficulties in the construction stage. Therefore, BIM is considered as an appropriate tool in reducing reworks which we discuss later.

Considering the concepts contained in TQM as well as the capabilities available in BIM during the life cycle of the project, and since BIM is a new methodology and tool in the project industry, it is possible to use these capabilities in implementing of TQM in projects. Table 10 summarizes the relationship between BIM and TQM where, BIM could be considered as an effective tool for covering and implementing the some important elements of TQM in projects.

**Table 10.** TQM elements & BIM capabilities

| Capabilities number | Building information modeling capabilities | Elements of total quality management in projects |
|---|---|---|
| 15-14 | Integrated design and IPD system and use of the perspective of all stakeholders in the virtual design of the project | Teamwork at all levels of the project |
| 13-7-6-2 | 'The use of a set of advanced software and 3D modeling and simulation of the design process before the stage of construction and use of the best construction method. | Continuous improvement in work and technology use |
| 13-7-2 | Create a parametric n-dimensional model and construct a virtual model before implementing the project and create the appropriate visibility among all the project components. | Obtain satisfaction from the employer and all stakeholders |
| All capabilities | More focus on design and information modeling and simulation of the pre-run manufacturing process | Spend more time setting up a quality assurance system in the project |
| 4-7-14-15 | Including vendor and material information on model and metric, and accurate refinement of materials and use of suppliers' opinions on project design and material selection. | Procurement and management of suppliers |
| 5 | The ability to document and measure knowledge and use this information in future projects | Training human resources and the use of lessons learned |
| 15-14-12 | Secure design and identify model risks and create collaborative culture in the project team | Leadership Commitment and Project Management |

In the following sections, we will focus on the role of BIM in overcoming the factors that cause rework:

### 3-2- Weak and disorganized communications

BIM is based on the integrated design and cooperation of the (mai\\n and key) stakeholders of the project in the production of the building information model; the goal is to ultimately turn this virtual information model into the desired project. With this approach, the advisor is not the sole person responsible for designing the project, and the contractors and suppliers besides the project client and project utilizers, play a significant role in the production-of-information-model stage. This, from the very beginning, leads to formation of clear communications between all of the project factors; and also causes appropriate consideration of all their needs in the offered plan. On the other hand, the attachment of the information on the project information model contributes to the clarification of the things demanded by all of the stakeholders. Finally, the highest level of cooperation can be accomplished by applying IPD system on the project execution; a system which coordinates all of the working groups and contributes to the general success of the project (not just to the organization’s benefit). Figure 9 displays the communication [network] of the project factors in traditional systems and BIM.

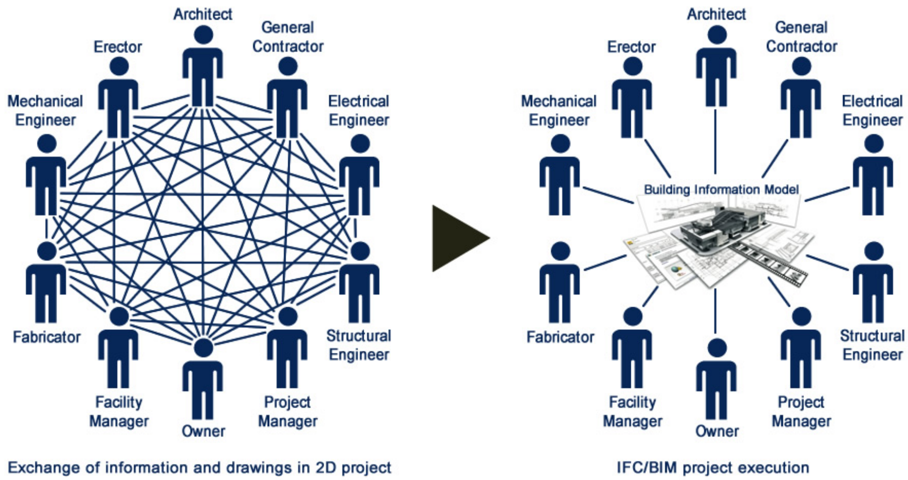


**Fig 9.** The Communication [network] of the Project Factors in Traditional Systems and BIM

### 3-3- Inefficient use of IT and technologies

BIM coincides with IT. The model provided by BIM collects all the project data of various phases on a 3D model, this model is accessible online to all of the main project stakeholders. This significantly reduces documents exchanges and their resulting rework. The role of technology in BIM is so outstanding that the programs and plugins that try to facilitate its use are published on a daily basis in order to help overcome the projects' problems.

### 3-4- Mistakes and negligence, and incorrect views of the project

Lack of understanding regarding the needs of the project, not recognizing the demands of the main stakeholders, and the lack of clients' proper understanding (caused by the clients incorrect view of the project) regarding the offered plan/design by the design team, constitute the major mistakes and negligences in understanding the project. Methods such as BIM, through providing a multi-dimensional model (3D, construction process simulation, quantity surveying and cost estimation) and building a virtual information model of the project, help us to have a comprehensive and proper view of the project and to meet all of the clients' demands in our information model before launching the construction phase. The mentioned point reduces the probability of legal conflicts between project factors and also reduces the reworks caused by the changes made by the client.

### 3-5- Weak planning, and assignment of insufficient time to planning and design [processes]

A most obvious characteristics of BIM is the assignment of more time and energy to the project designing and planning processes (by using the views of all key stakeholders), production of an information model, and a more accurate planning during the design phase and before entering the construction phase; in order to accomplish a flawless information model- without any conflicts between various disciplines- that is approved by all of the main stakeholders. All of these works are done to dramatically reduce any chance of rework. By doing so the production of the information model and goal setting are done more accurately and thus promote the project quality. Figure 10 compares BIM with other traditional systems regarding the amount of concentration needed for different project phases.

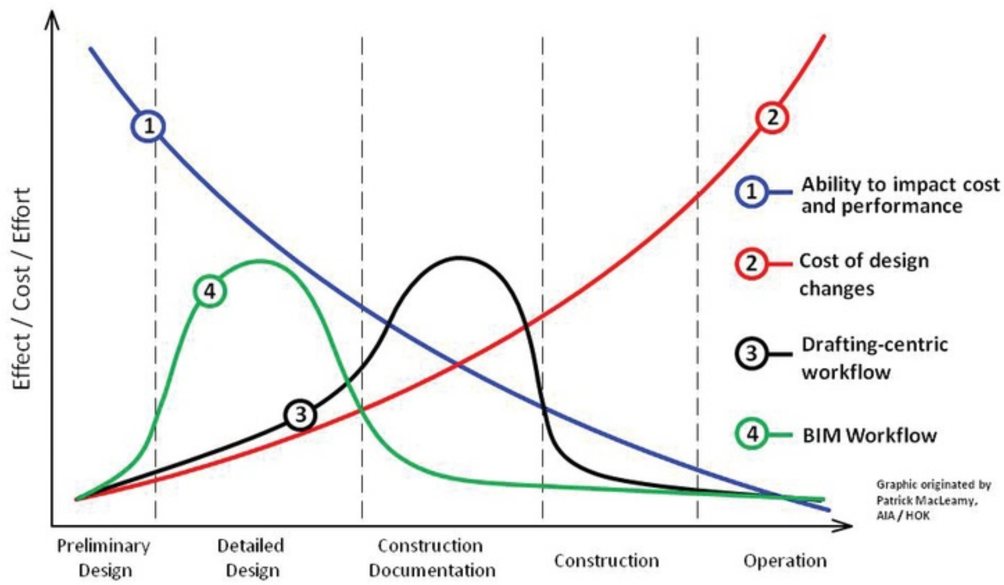


**Fig 10.** BIM and traditional systems comparison regarding concertation variations

### 3-6- Using weak materials, and low-quality suppliers

Writing the quantity and quality information of the used materials and equipment, the information model showing of the accurate details of the material in the design, and the attachment of the required work standard for the project execution on the information model, more than ever and anything, make the contractors and suppliers to regard the needed quality according to the plans. Moreover, the IPD method involves the supplier in the project as one of the key stakeholders in order to use their point of view in the pre-construction process and ultimately results in suppliers' use of the superior material in accordance with their own benefits and treats them as a partner.

### 3-7- Unskilled employees/workers and the lack of skilled workforce

One way of promoting the workers/employees level of skills is constant training combined with knowledge management and the use of learnings from the previous projects. The information model built through BIM, on its own, is a comprehensive documentation of the project, and the information of this model can be regarded as learnings to be used for the training of the workers for the future projects.

### 3-8- Insecure and inappropriate work environment

The BIM tool is regarded as a tool available for the enhancement of the safety and the health of the workforce. BIM can be used for workforce training, construction site designing (based on safety standards), safety planning (analyzing the dangers of work), analyzing and identifying risk management factors, determining the equipment (for example excavation equipment) motion scope, determining the material and parts storage place, identifying the accidents in the site, and maintaining safety measures during the utilization phase. Through building a shared 3D model of the building, BIM reduces the probability of risks and increases the chance of identifying them, for the parties involved in the design and construction phases.

It was obserSSSved how BIM leads to a reduction of rework in the project. The following process models show the method of implementing BIM, for increasing the quality and application of TQM. In figure 11, the BIM proposed process model for implementation TQM.

In order to investigate the effect of building information modeling on reducing reworking, a survey was conducted by experts and faculty members in the field of building information modeling to show how much building information modeling affects on each of the reworking factors. The numbers obtained by each person are obtained by the Likert scasle and the 3 parameter beta distribution, and finally the geometric mean is obtained from the numbers obtained by different individuals (summarized in the table below). Assuming that all the reworking factors are the same, from the numbers obtained, the mean of the arithmetic is taken, which is roughly modeling the information of 60% (relatively high) on the reworkings, which has a positive effect and reduces these factors (table 11).

**Table 11.** the effect of building information modeling on reducing reworking

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| 69.71 | 84.48 | 72.36 | 82.73 | 44.53 | 15.16 | 56.66 |
| 60.80=Average | | | | | | |

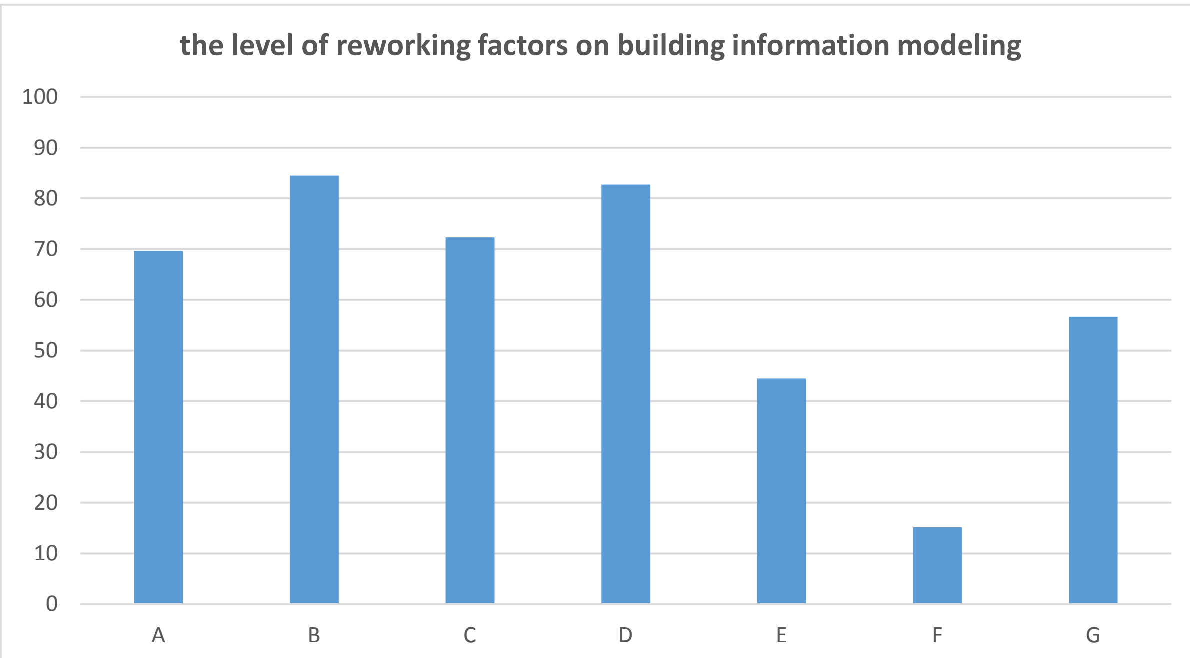


**Fig 11.** The level of reworking factors on building information modeling

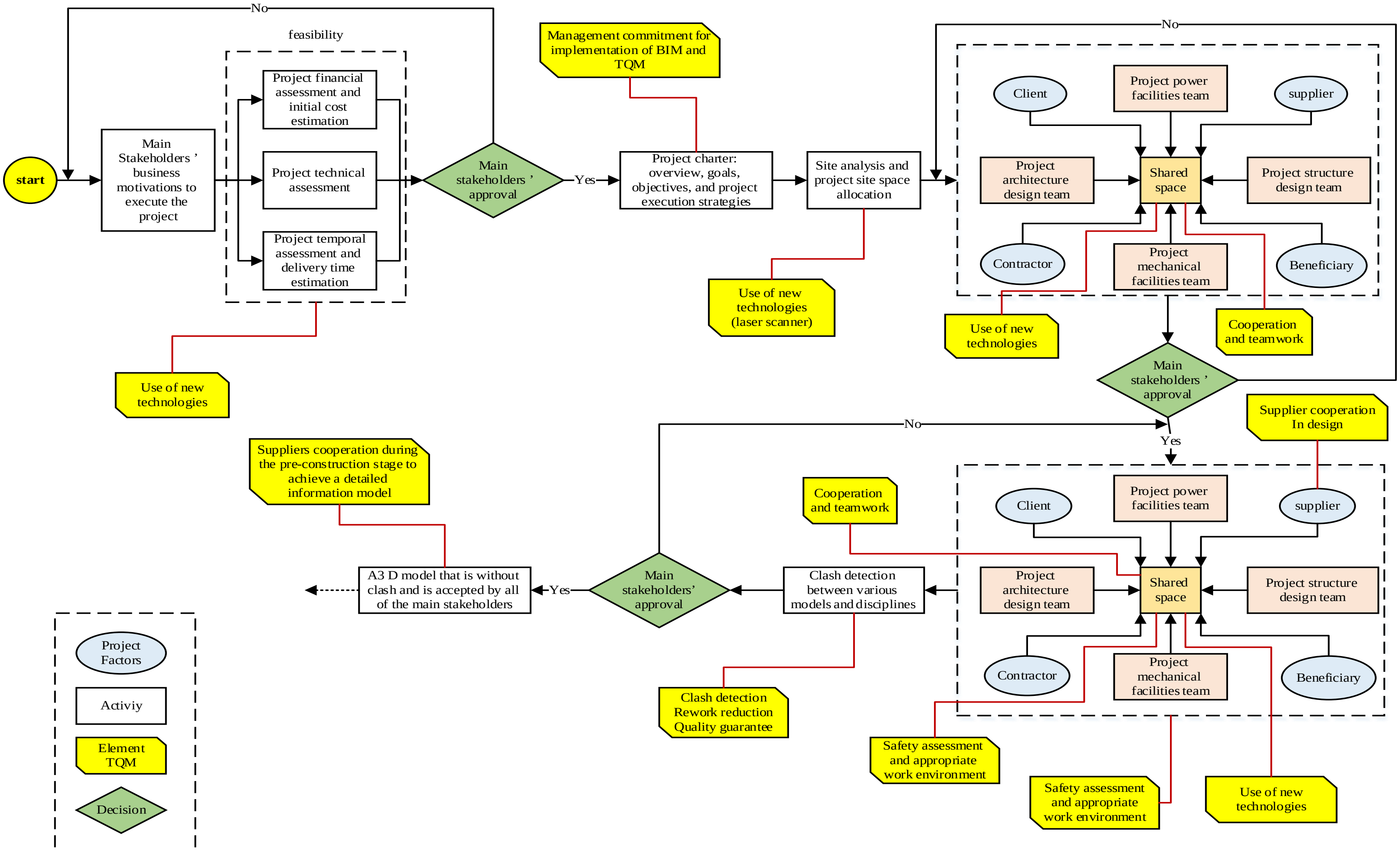


**Fig 12.** Implementation process model BIM

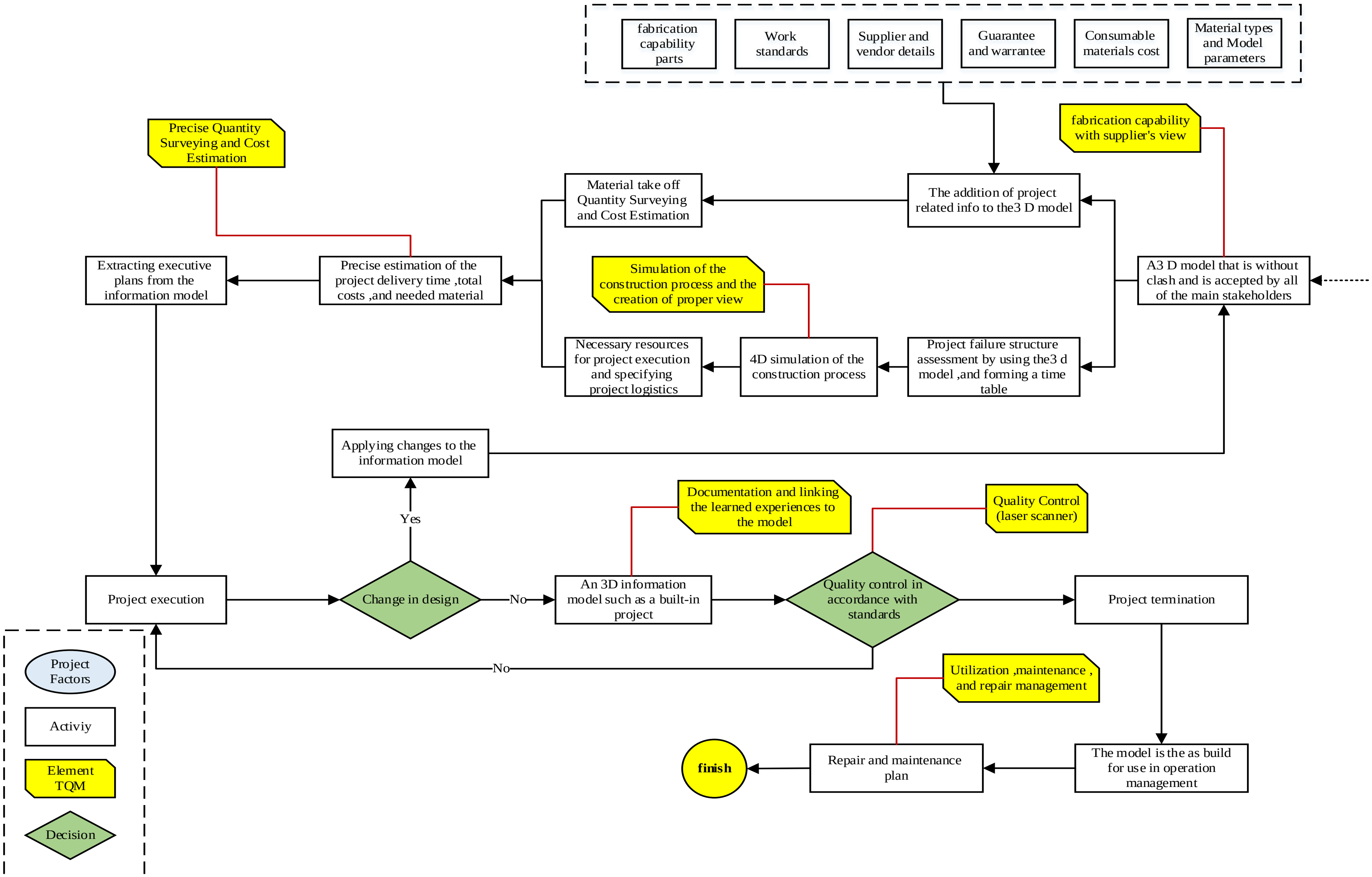


**Fig 12.** Implementation process model BIM (continue)

## 4- Conclusion

As it was observed throughout the paper, it can be concluded that the natural characteristics of BIM have an intimate relationship with increasing and promoting of the project's quality measures. We mentioned 7 reasons that constitute the main factors that lead to rework in the projects, and by using TQM and its principles we tried to eliminate these factors. However, such an elimination of the rework factors was faced with some challenges, and BIM-as a tool- to a great extent was able to overcome these challenges. The table below summarizes the capabilities of BIM that can reduce 'rework' in the projects.

**Table 12.** Rework reduction through BIM

| The Causes of Rework | Solutions to Reduce Rework | BIM Capabilities |
|---|---|---|
| Weak communications and conflict between project factors | Effective and comprehensive use of the workforce, and teamwork on all levels | Integrated design, IPD system, and involving all of the stakeholders POV in the virtual project design |
| Inefficient use of IT | Using new technologies of the project management field and constant improvement of work | Collective use of advanced software |
| Errors and negligence, and clients' and stakeholders' inappropriate view of the project | Gaining the satisfaction of the client, and focusing on the workforce in order to reduce errors and negligence | Making an nD parametric model, making a virtual model before project execution, and making an forming view in the parties |
| Weak planning as a result of not assigning enough time to the planning and designing processes | Assigning more time to the design process and more precision in calculations | More concentration on the designing and the information model |
| Using low-quality materials and low-quality suppliers | Managing suppliers and treating them like stakeholders/partners | Mentioning the vendors and materials info on the model |
| Workers not having the required abilities and lack of a skilled workforce | Training the human resources and using the experiences from previous projects | The capacity for knowledge management and documentation |
| The insecure and inappropriate work environment | Project management's responsibility and support for meeting the standards of the project | Safe design and model risk detection |

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