

Article

Materials Challenges in Reconstruction of Historical Projects: A Case Study of the Old Riwaq Project

Basem Al Khatib, Yap Soon Poh and Ahmed El-Shafie * 

Department of Civil Engineering, Faculty of Engineering, University Malaya, Kuala Lumpur 50603, Malaysia

* Correspondence: elshafie@um.edu.my; Tel.: +60-3-7967-7651

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Abstract: Nowadays, the focus on sustainable materials with high specifications has become a necessity in certain important construction projects. These materials play an essential role and constitute the foundation stone in the sustainability of these projects in addition to their impact on the execution time. Many studies have discussed the challenges faced by these materials and their negative impact on the execution period of construction projects. However, these studies are still scarce in the reconstruction projects, especially the historical ones, which are based mainly on the sustainability of the materials used, which are represented by the historical elements that maintain the ancient shape of the building. The aim of this research is to highlight the materials-related challenges of historical reconstruction projects which negatively affect the planned duration of implementation. This study was conducted on the Old Riwaq project, which is the historical part of the Mataf Expansion project in the city of Mecca, Saudi Arabia. It is considered one of the most important reconstruction historical projects that have been recently carried out in the Middle East. In order to achieve this goal, 15 interviews were held with the engineers working in this project and specialists in these types of historical projects. The results show a group of different challenges that follow the reconstruction stages of the historical building. These challenges are: challenges related to the first stage which is the documentation and dismantling stage (two challenges), challenges related to the second stage which is the workshops stage (three challenges), and challenges related to the third stage which is the new designs and mockup stage (three challenges). Finally, the identification of sustainable materials challenges should be considered an urgent necessity, in order to overcome or reduce their negative effects in future projects, especially in relation to project durations.

Keywords: historical buildings; project duration; sustainable materials; Mecca; materials challenges; Middle East

1. Introduction

There are many challenges and problems facing construction projects, which have a negative impact on this industry. In fact, the challenges in the construction industry are clearly affecting countries in many aspects, such as the economy and the sustainable development goals [1,2]. One of these important challenges relates to materials required for construction projects. There are several studies that have pointed to these challenges for being among the main reasons for increasing project duration, and thus delaying the delivery date [3]. Actually, delayed projects are usually accompanied by an increase in the cost for either the contractor, the owner, or both. In addition, this negative effect on the relation between the different parties might affect project sustainability [4,5]. Referring to previous studies, it is noted that most have pointed to the challenges facing the materials related to new construction projects. The results of these studies show a direct correlation between these challenges and project delays. On the other hand, it is clearly noted that studies of reconstruction projects are still few, particularly reconstruction projects of historical buildings. The purpose of reconstruction

projects is usually to obtain buildings with more capacity, or to improve and update various electrical and mechanical systems or for safety and stability reasons, or commercial reasons [6]. The reason for historical buildings reconstructions is the damage of these buildings over time, usually caused by weather conditions, erosion, natural disasters like earthquakes, volcanoes, floods, or because of wars. These reasons make the reconstruction of the historical building a necessity for safety and stability of the building and the safety of the visitors. In addition, the reconstruction may be for logistical reasons and the need to expand and develop a building's various services.

This study aims to highlight and discuss the materials-related challenges in reconstruction of historical projects, in order to save the implementation period and as a result to save the execution cost due to the clear correlation between time/cost in the construction industry. Additionally, this research also could contribute to forming a platform for a similar future research, in the form of a database illustrating the various challenges that can face such projects. In fact, this issue was discussed by several interviews with the experts who worked in the Old Riwaq project, which is one of the most important historical projects recently reconstructed in the Middle East.

This work identifies materials-related challenges, in order to reduce time/cost for a reconstruction project, subsequently contributing to sustainable construction.

Several studies on construction projects have mentioned materials-related challenges that arose during project execution. The challenges can be categorized as: (i) shortage of materials [7–24]; (ii) challenges related to the late delivery of materials [7,14–16,25–34]; (iii) challenges related to the fluctuations and escalation of material price [11,18,22,32,35–38]; (iv) challenges related to the long duration of materials procurement [3,33,35,39]; (v) challenges related to changes of material [13,40]; (vi) challenges related to poor quality of materials; and (vii) challenges related to imported materials [41].

2. Research Methodology

Table 1 displays the summary of challenges related to the construction materials which have had a negative effect on project duration, as discussed in the previous studies. In addition, Table 1 shows the many reasons behind these challenges. The main objective of this table was to draw the attention of the experts interviewed to the significance of this subject, as it was a motivation for them to mention the challenges that they faced related to the materials during the reconstruction of the Old Riwaq project. It represents a case study on this type of historical projects reconstruction. This project is characterized by its historical value and it is one of the Mataf extension projects. It is worth mentioning that these projects are implemented in phases because of the impossibility of closing them completely and isolating them, due to their importance and the large number of its visitors throughout the year.

Table 1. Material related challenges with associated reasons.

No.	Challenge	Main Reason	Reference
I	Shortage of materials	Providing wrong estimation. Damages during handling materials and poor inventory management system. Delay in payments and financial problems. Construction defective and mistakes. Scope of works changes. Late identification of the type of materials needed.	[7–24]
II	Late delivery of materials	Delay in payments and financial problems. Delay in procurement of materials. Customs clearance for imported material. Slowness in decision making.	[7,14–16,25–34]
III	Fluctuations and Escalation of material price	Change in the cost of raw materials. Changes in market conditions and Shortage of supplies. Instability in local currencies exchange rates and increasing of Inflation rates. The additional cost of transport and import duties. Rising labor or production costs in the supply chain.	[11,18,22,32,35–38]

Table 1. Cont.

No.	Challenge	Main Reason	Reference
IV	Long duration of materials procurement	Delay in finalizing material take of list, as well as materials shop drawings. Contractor delay in submission the technical requirement for the consultant's approval. Delay in consultant's reviewing and approval. Spending long time in supplier price negotiation and financial problems.	[3,33,35,39]
V	Changes of material	Design changes. Scope of works changes. The lead time of material delivery. Late initiation of value engineering process.	[13,40]
VI	Poor quality of materials	Selecting poor source of materials. Lack of quality control and assurance systems. Bad shipping and storage handling. Cheap construction materials. Lack of materials test and inspection.	[11,32]
VII	Imported materials	Delays in placing purchase orders for imported materials. Long period of delivery. Custom clearance procedures. Seasons such as festivals, vacations, winters, etc. affects the processing procedure.	[41]

Fifteen interviews were carried out with the experts working in the Old Riwaq project in different levels in the organization chart of this historical project, with some of them working in the day shift and others working in the night shift. The interviewees included one project manager, one construction manager, two planning and scheduling engineers, two senior site engineers, five site engineers, and four engineers working in the technical office as technical engineers. All experts interviewed in this project had at least six years of experience in the construction industry. The main target of these interview sessions was to highlight the materials-related challenges of historical reconstruction projects which negatively affect the project duration. Moreover, the sample size "15 interviewees" in such a qualitative research method that depends on the interviews in order to gather the required data and other information, can be identified through saturation. This means that any further interview sessions that do not produce new data or information might be omitted from the study [42]. In fact, this subject was achieved by two additional interview sessions with a construction manager and project manager who worked in the night shift, in order to confirm the results of the 15 interview sessions.

The project was visited several times in order to choose suitable times for the experts to be interviewed. In fact, the objective of this step is for the expert to feel comfortable during the interview and to have enough time to mention all the challenges they faced and everything related to it during work on the project. In order to secure suitable interview times, tables and papers were prepared that facilitated the registration of all the information mentioned by the experts. The research methodology and framework is summarized in Figure 1.

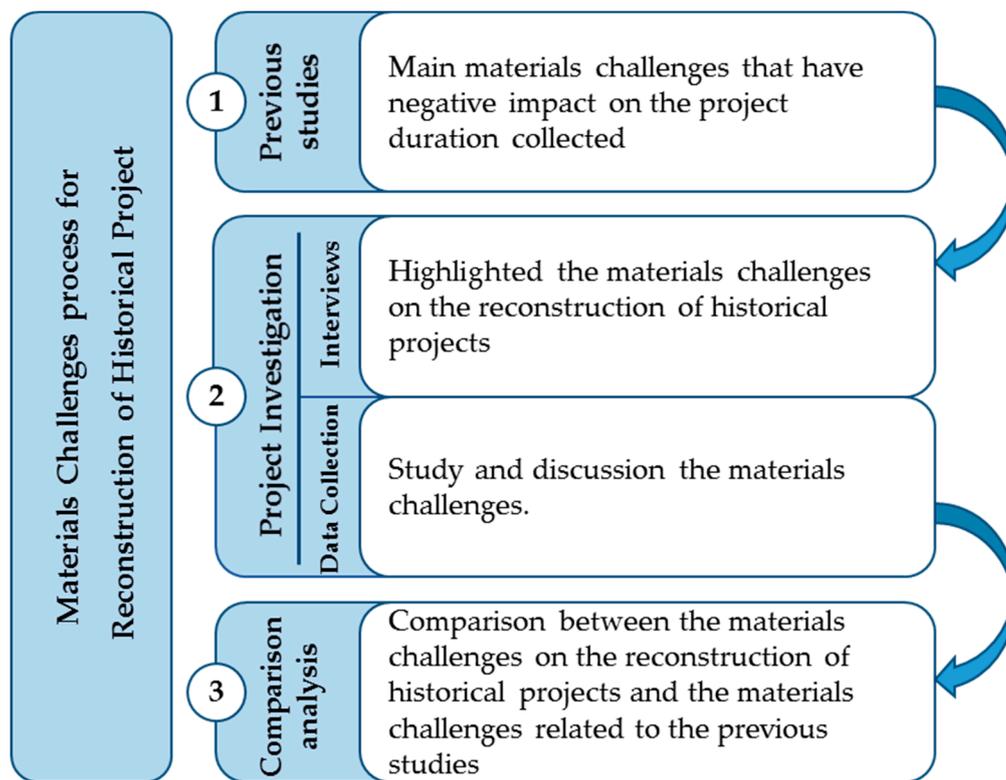


Figure 1. Research methodology and framework.

The first interview of the project was with the project manager with considerable experience in this type of historical reconstruction projects where the challenges gathered through the previous studies were discussed. During this interview, the project manager explained that the materials-related challenges in this type of project are distinct from other construction projects. He stated that working on historical reconstruction projects is divided into a series of phases and each stage has encountered a range of challenges that are different from the other stages. During the interview, the project manager indicated that working on the Old Riwaq project could be divided into two main phases; the first stage is the documentation and dismantling of the historical building, while the second is the workshops stage.

The challenges mentioned by the project manager related to the previous two phases were discussed and recorded. He also recommended two questions to be asked to the engineers working in the project during the interviews and giving them an opportunity to mention the challenges that faced them during the execution work. These questions are:

In your view as an expert working on this project, what are the materials-related challenges that have been associated with the documentation and dismantling of the historical building?

What are the materials-related challenges associated with the workshop phase?

In fact, this first interview with the project manager was very important and resulted in the preparation of a new working paper which included the two previous questions as the basis for the rest of the interviews with the experts working in the project.

The second interview was conducted with the construction manager where the new working paper was discussed containing the two questions proposed by the project manager in order to identify the challenges of the project materials.

The construction manager mentioned several challenges that characterized each phase of the project, where they were recorded and discussed.

In fact, as an expert working on the project, the construction manager suggested a third question to be added to the working paper concerning the new designs and mockup stage. He pointed out that

this phase can be separated from the phase of the workshops and considered as the third phase of the project, where it is characterized by a special set of challenges. The construction manager noted that adding a specific question related to this stage would make it easier for the experts to be interviewed later to mention the materials-related challenges encountered during the execution works in a clearer and more detailed way.

In fact, the second interview with the construction manager resulted in the final form of the new working paper which included the two previous questions in addition to a third question.

What are the materials-related challenges that have been associated with the new designs and mockup stage?

3. Case Study and Data Collection

Figure 2 shows the location of the Old Riwaq project, which is part of the Mataf Expansion project projects in Mecca in Saudi Arabia. During the interviews, the experts mentioned that the work in this project was divided into three main phases as shown in Figures 3 and 4. That is because of the special location and the great importance of the project, which prevent it being closed completely.

In each phase of the Old Riwaq project the results of the interviews indicate the existence of several different challenges that follow the reconstruction stages. These stages are the same in each phase which is as the following:

1. Documentation and dismantling stage (Section 3.1);
2. Workshops stage (Section 3.2);
3. New designs and mockup stage (Section 3.3).

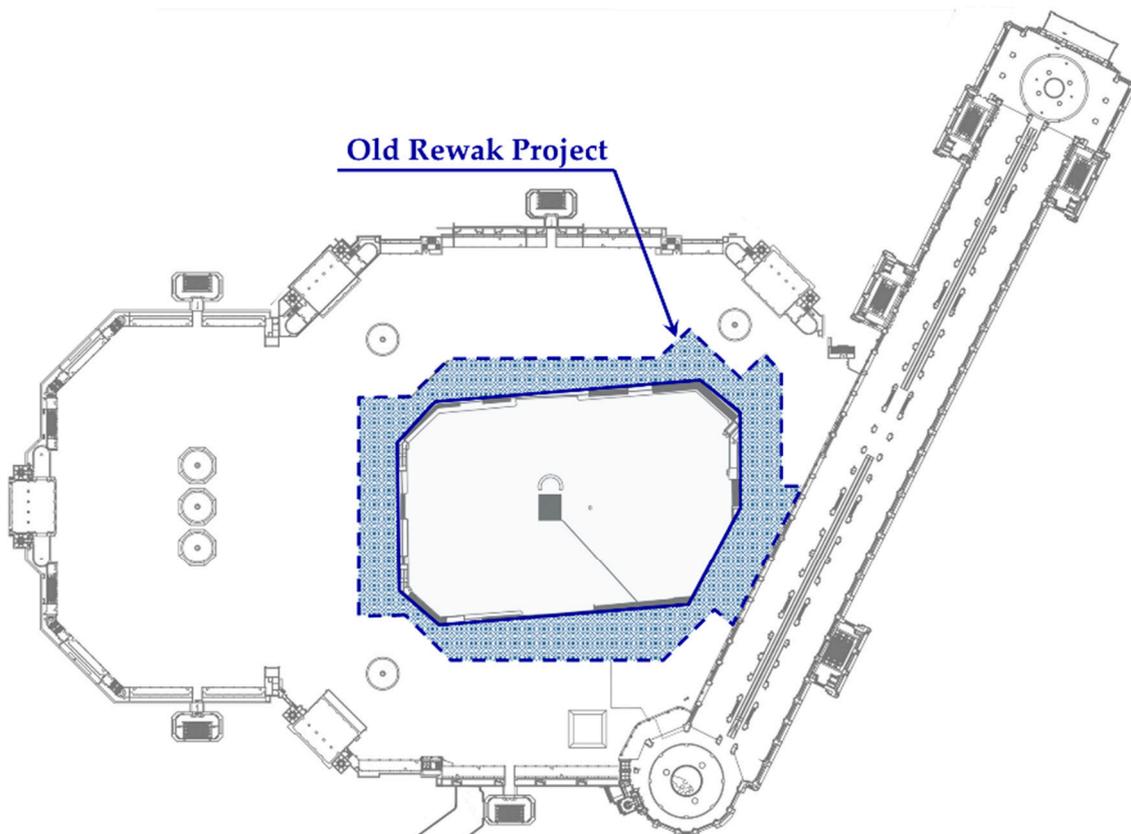


Figure 2. The location of the Old Riwaq project.

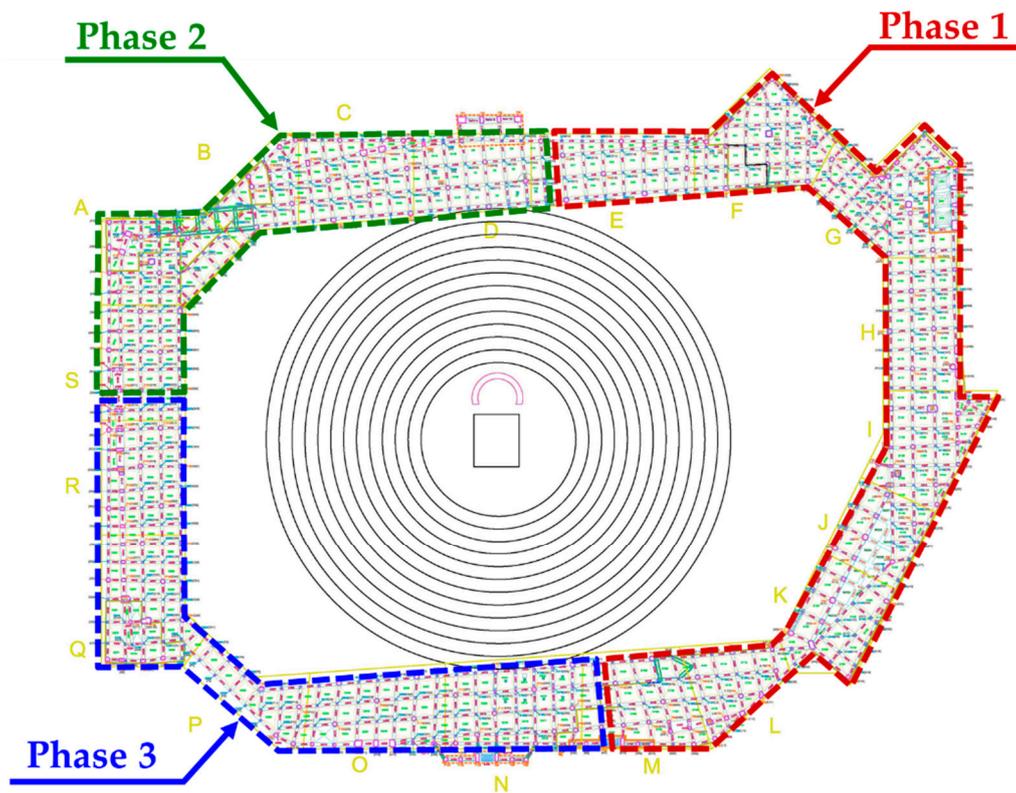


Figure 3. Main reconstruction phases of Old Riwaq project.

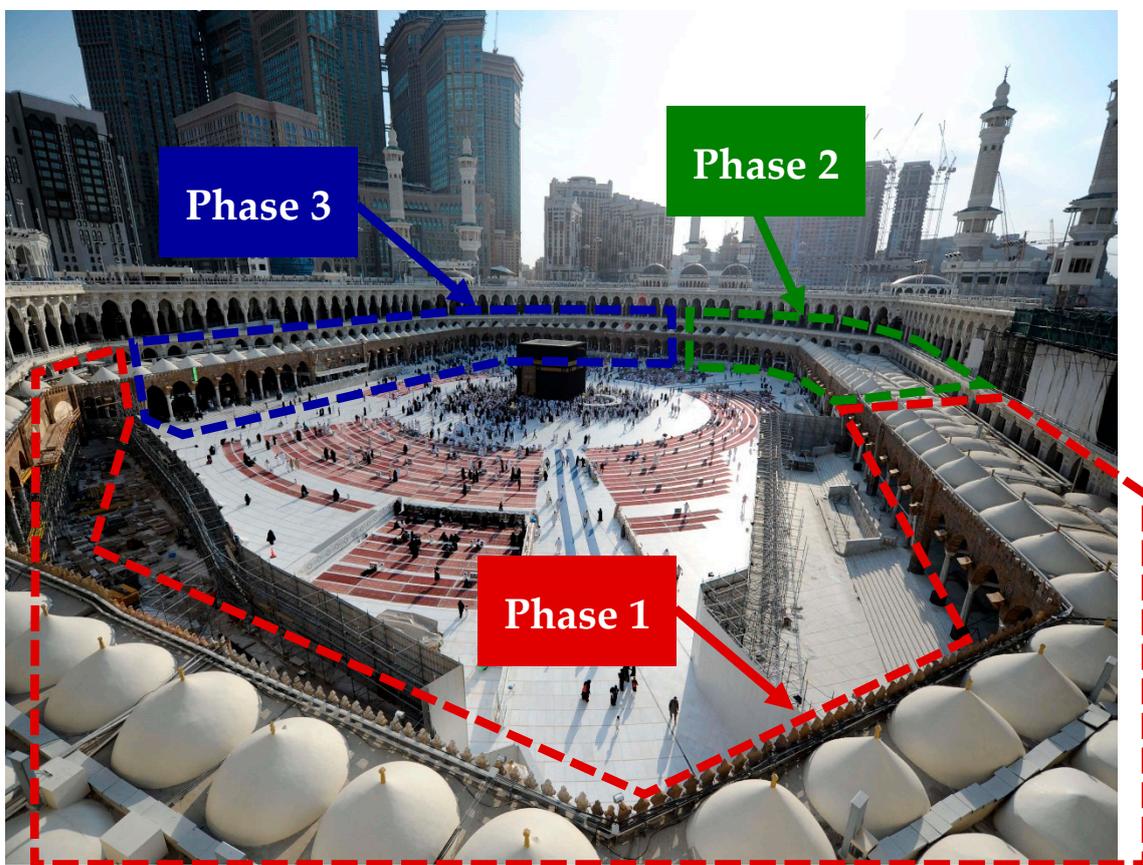


Figure 4. Phases of the Old Riwaq project.

3.1. Documentation and Dismantling Stage

The first step in this historical project was the documentation work, as the experts mentioned in the interviews. Actually, before starting the dismantling procedures for the building, it was necessary to do the surveying works using modern surveying instruments and expert surveyors specialized in this type of historical project, in addition to different types of photography with high quality and resolution. In fact, the aim of this work is to prepare an accurate as-built drawing that shows the location of each element in the historical building, alongside the photos, which play a fundamental role in the historic documentation of the project. The shape and the condition of each element in the building were also documented because of the great historical value of the project. The experts pointed out that they could not start the dismantling works in any phase until the completion of the documentation works, which affected the reconstruction time of the project.

The second challenge in this stage was the numbering of the historical elements, dismantling works, protecting, packaging and transportation them in special wooden boxes to the workshop areas. In fact, this is considered a very important step in order to maintain the sustainability and the style of the historical elements. Figures 4–8 show some of these works related to the historical columns which were divided into three parts for safety and sustainability purposes: the capital, the body and the base. These parts were numbered, dismantled, protected, and packaged.

Figures 9–12 show the numbering works for the historical stones, the dismantling works for the domes, the facade stones, and the dismantling works for the arches. All the historical stones were protected, packed and transported to the workshop areas. The experts mentioned that the previous works required special and manual dismantling tools. In spite of the availability of the skilled laborers, however these works required a long period that negatively affected the project duration.



Figure 5. Numbering the column body.



Figure 6. Numbering the column capital.



Figure 7. Protecting and packing the column.



Figure 8. Column dismantling.



Figure 9. Numbering the historical stones.



Figure 10. Domes dismantling.



Figure 11. Facade stones dismantling.



Figure 12. Arches stones dismantling.

3.2. Workshops Stage

After transferring the historical elements to the workshop areas, the next stage works started by unpacking, sorting and arranging the different elements. Many tables were prepared showing the total number of the similar historical items. Figures 13–16 show the unpacking and sorting works for the stones and the columns.

Table 2 displays the summary of the historical items belonging to the first phase of the project after the completion of sorting and arranging works within the workshops area.



Figure 13. Unpacking works.



Figure 14. Unpacking and sorting works.



Figure 15. Sorting works for the stones.



Figure 16. Sorting for the stones and the columns.

Table 2. Inventories of dismantled items (1st Phase).

Elements	Item
Marble column	88
Capital	92
Base	70
Profile stone	50
Arch stone	1491
Finial	48
Keystone of arches	15
Shemasi pillar stone	678

Table 2. Cont.

Elements	Item
Egyptian gate	112
Cornices	461
Muqarnas	82
Parapet stone	215
Rosette	45
Script	17

The historical items were carefully tested by using special equipment in order to identify their stability and conditions. After that, they were re-documented by using many tables that show the measurements and photos as well as the status for each item. Using the previous tables, the design consultant selected the items that would be reconstructed again in the project location. Actually, this selection was made according to the aesthetical and the historical value of each item as well as the structural applicability and sustainability.

The experts mentioned that the selected items were treated through a series of activities according to the item condition. The first activity was the cleaning works which divided into two steps. The step one was the surface cleaning by using soft brushes and small spatulas, while the step two was the deep cleaning by using the chemical materials in order to remove the grease and oil stains, as well as cleaning the joints and spaces as shown in Figures 17 and 18.



Figure 17. Surface cleaning of a column base.



Figure 18. Deep cleaning of a column body.

It is worth mentioning that during the cleaning works, imitations were removed which revealed old treatments that were made to historical elements over the years, which were not compatible with

the nature of these elements. The experts pointed out that the previous works were very important in order to know the amount of damage in the historical items.

The final step in this stage was the restoration work, which depends on the amount of damage for each item. In fact, the restoration works were divided into two main types. The first type is related to surface damages and cracks. This type was restored by using special chemical substances that were mixed with a powder similar to the nature of the architectural item. The results were a mortar similar to the historical item with high sustainability used to restore the surface damages and the cracks. However, the second type of the restoration is related to the joining of two pieces or more of the historical item together by using chemical substances in addition to special steel anchors if necessary. Actually, sometimes the joining pieces could be from the same historical item, as shown in Figures 19–22.



Figure 19. Chemical substances applied.



Figure 20. Steel anchors utilized.



Figure 21. Stone pieces joined.



Figure 22. Stone shape after restoration.

However, sometimes a new piece could be joined which possessed the same nature of the historical item, as shown in Figures 23 and 24.



Figure 23. Chemical substances and anchors applied.



Figure 24. Marble column after restoration.

The experts emphasized that the previous steps were considered as a big challenge especially in terms of time. In fact, restoration of the historical items was done in the workshop areas, which negatively affected the project duration.

3.3. New Designs and Mockup Stage

The designs show the historical restoration materials and other similar materials that should be used in the reconstruction works. However, the final shape, location and connection between these

materials are subject to a mockup being made in order to display these details and avoid any clashes in the integrated designs before starting the reconstruction works at the project site.

Actually, the design team faced many challenges while preparing the new designs for this historical project, as the experts mentioned during the interviews. Actually, the first challenge was related to the new form of the project which has to simulate the previous one through the preservation of spirit and the ancient shape of the old building which had been dismantled from the project site. The second challenge is related to the project level. Indeed, the old project was built on different levels, however the new historical building has to be constructed on one level, the lowest level in the project. This design would facilitate the movement and the flow of the visitors easily. In addition, the safety and sustainability challenge was a very important one for the new building. In fact, this challenge added many constraints on the new structure design in order for the safety and sustainability requirements and criteria to be met.

The new design approval from all the related parties before proceeding with the reconstruction works at site was subject to the building of a mockup showing all the details related to the structure, mechanical, plumbing and electrical design. In fact, the execution of the mockup was the final outcome of all the above-mentioned stages and challenges, as mentioned by the experts in the project, as it was the penultimate step preceding the reconstruction of the Old Riwaq at the project site. In addition, during the interviews many purposes for the mockup were mentioned such as: testing the best and fastest methods for the reconstruction works, especially the formwork systems and the required equipment; testing the design constructability and conflicts; showing the shape of the restoration elements after the installation works and the final integration form of the project; testing the sustainability and the safety requirement for the new reconstruction building; and to obtain approvals from the consultant and other entities in order to start the actual reconstruction works at site. Figures 25 and 26 show the three-dimensional module for the new design and the new historical building mockup.

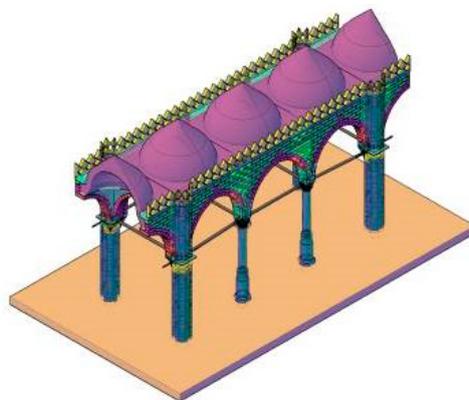


Figure 25. 3D module for the new design.



Figure 26. New historical building mockup.

Actually, the experts pointed out that the previous works related to the new design and the mockup requirements were a big challenge in terms of time, and affected the project duration negatively.

4. Discussion

All the challenges mentioned during the interviews and those that had a negative impact on the project duration were recorded and discussed with the experts working on the Old Riwaq project. It became clear from the results of the interviews that there was consensus and similarity between the views of the experts regarding these challenges. In fact, the materials-related challenges were divided into three groups according to the reconstruction stages of the historical project as follows:

The first stage was the documentation and dismantling of the historical building. In this stage the results indicate that there were two major challenges:

- Surveying works and the preparation of accurate as-built drawings that show the building shape and the location of each element in the historical building.
- Numbering of the historical elements, dismantling works, packaging and transportation to the workshop areas where the second stage of work begins.

The second stage of the project was the workshops stage, characterized by three main challenges:

- Sorting, testing and arranging the historical elements according to their structural stability and sustainability.
- Cleaning the historical items from the dirt, grease and oil stains in addition to removing the imitations.
- Restoration of historical elements using different methods and techniques depending on the condition of each item by applying special substances.

The third stage in this project was the new design and mockup stage, which faced three major challenges:

- Design requirements, especially the overall form, which had to simulate the old building and the new project level, which had to make movement and flow for the visitors more easy, as well as conforming to safety and sustainability criteria.
- Building a mockup showing the final shape of the new historical building based on the new integrated designs and the restoration items.
- The speed of obtaining the required consultant and other entities approvals in order to start the actual reconstruction works at site.

It was clear by reviewing the previous studies that the last challenge, which is related to the required consultant and other entities approvals, is similar to the previous studies. The other challenges mentioned above distinguish the materials related to this type of historical project and negatively affect the project time, as experts mentioned during the interviews. Figure 27 summarizes all the challenges encountered at each stage of the project.

It is noteworthy that the previous challenges were evident during the work in the first phase area of the project, as experts agreed during the interviews. In fact, the expert team was able to mitigate the negative effects of these challenges and overcome many of them within the remaining project phases through new plans that took into account all the challenges that emerged in the first phase of the project. The new plans were reflected on the execution methodology and included a series of corrective actions, which were as follows:

- Completing the documentation works, surveying and photographing of the remaining project phases during the construction of first phase of the project. This resulted in shortening the time required of remaining phases and accelerating the start of the dismantling works within the second and third phase of the project.

- Developing the scaffolding, back propping and formwork systems, which accelerated the installation of these systems and facilitated the movement of workers as well as the transfer of historical elements.
- Dividing the workshops into many areas and providing these areas with specialized teams, as follows:
 - Specialized teams in surface cleaning of historical elements.
 - Deep cleaning teams.
 - Teams specialized in the restoration of columns (bases, column bodies and crowns).
 - Specialized teams working with stones restoration based on their different types.

These specialized teams resulted in shortening the working time within the workshop area and transforming them into production lines.

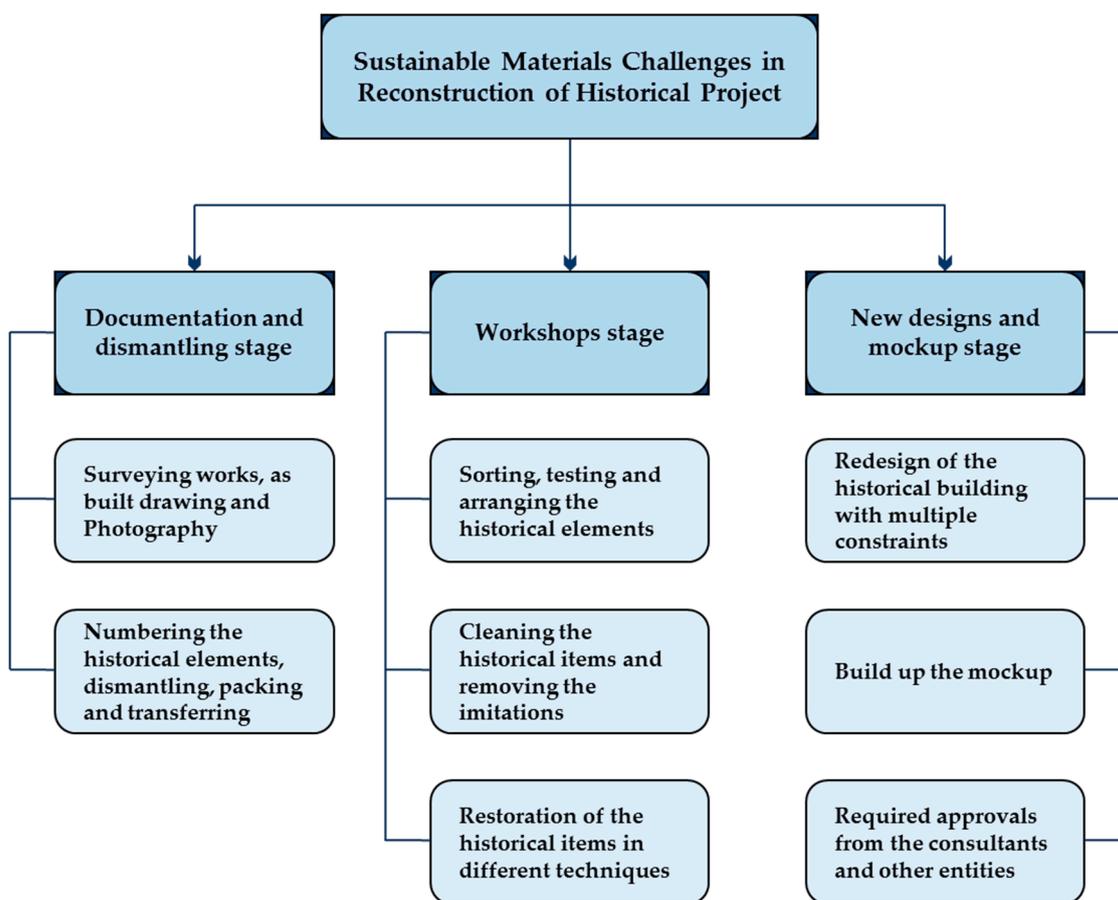


Figure 27. Summarized materials challenges in reconstruction of historical projects.

5. Conclusions

Planning for project resources before starting the construction phase, as well as following-up and controlling processes, are essential prerequisites for project sustainability in order to achieve project objectives on time. In fact, construction materials are one of the most important resources of a project and they play a key role in the execution phase and clearly affect the progress of the project and thus the time of implementation. Many studies have examined the challenges facing materials in construction projects, in order to avoid—or at least mitigate—the negative effects of these challenges especially on the project duration. However, such studies are still relatively few for reconstruction projects, particularly for reconstruction of historic buildings. In fact, historical projects are based mainly on the

sustainability of the historical item that formed the construction materials. This study was carried out on the Old Riwaq project, which is the historical part of the Mataf Expansion project in the city of Mecca, Saudi Arabia. It is considered one of the most important reconstructions of historical projects recently conducted in the Middle East. Fifteen interviews were conducted with project experts to define and discuss the challenges facing the materials in this type of project and their negative impact on the project duration. The results of the interviews indicate that the work in the historical project was divided into several stages. At each stage, the experts mentioned several challenges faced by the materials as follows: The first stage was the documentation and dismantling of the historical building. During this stage, the major challenges were: (i) surveying and photography works as well as the preparation of an accurate as-built drawings; (ii) numbering of the historical elements, dismantling works, packaging and transportation. The second stage was the workshops stage. The challenges that emerged during this stage were: (i) sorting, testing and arranging the historical elements; (ii) cleaning the historical items and removing the imitations; and (iii) restoration of historical elements using different methods and applying special substances. The third stage was the new designs and mockup stage. The challenges that showed during this stage were: (i) design requirements; (ii) building a mockup showing the final shape of the new historical building; and (vii) the speed of obtaining the required consultant and other entities approvals.

In addition, the results of the interviews showed that the previous challenges, that were evident in the first phase of the project, were lessons learned during the work in the later phases of the project. As a result, some of the challenges were overcome and other negative impacts were mitigated during the second and third phase of the project through the following: (i) developing new plans in order to start the documentation works early and accelerate subsequent works; (ii) modification of execution methods and techniques, as well as developing the scaffolding and formwork systems, which accelerated the dismantling works; and (iii) reorganizing the workshops with specialized teams in order to expedite the restoration works.

Finally, the results of the study show several challenges facing the materials in historical reconstruction projects, and they refer to a set of practical procedures that were followed in order to address these challenges and mitigate their negative impacts on the project time and cost. The impact of the previous challenges is reflected on the project sustainability, especially through the selection of the appropriate historical materials after conducting a careful examination and passing the required tests in accordance with the project standards and specifications.

6. Recommendations

The study also recommends several points as follows:

- I. The previous materials challenges should be studied carefully during the planning phase of similar projects.
- II. Time impacts for materials challenges should be examined in order to estimate a proper project period.
- III. Conducting further studies on historical projects to identify the various materials challenges that could delay the project execution.
- IV. Sort the materials challenges in the reconstruction of historical projects according to their impact on the project duration.

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