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Structural and Architectural Damage Aspects of Historic Renaissance Buildings in Egypt and the Proposed Rehabilitation Methods

Mohamed Abdelmegeed
Lecturer
Fayoum University
Egypt

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Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
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Structural and Architectural Damage Aspects of Historic Renaissance Buildings in Egypt and the Proposed Rehabilitation Methods

Mohamed Abdelmegeed

Abstract

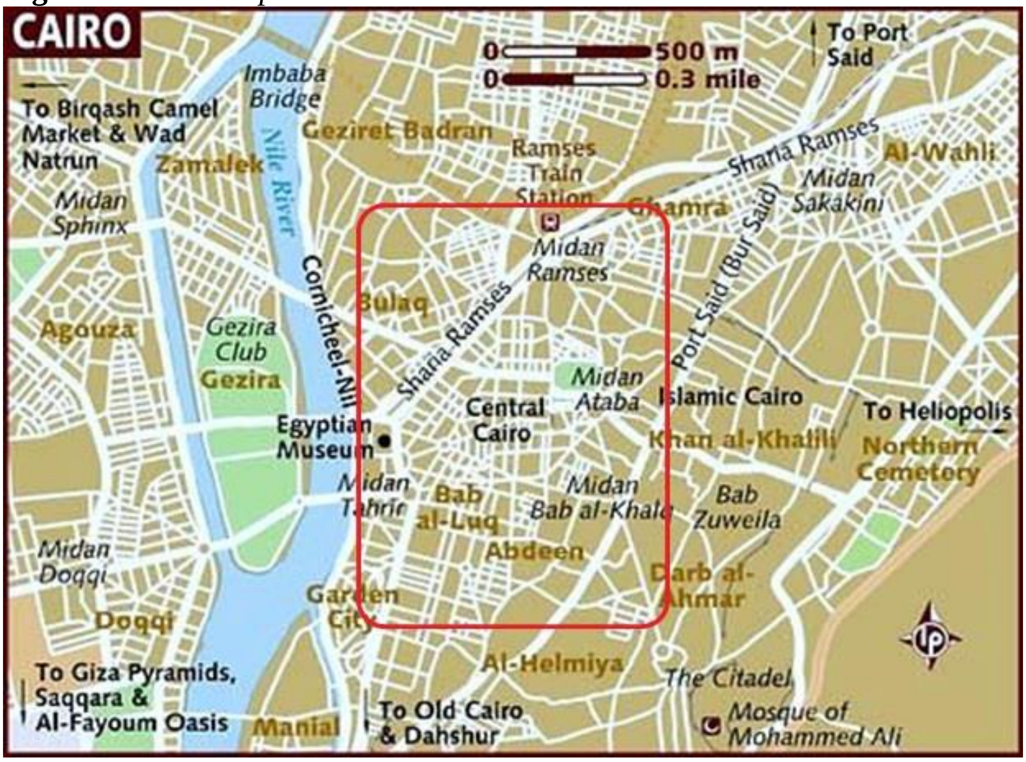
Historic renaissance structures are one of the most architecture forms that represent and demonstrate the architectural and cultural wealth of Egypt. It is works of art designed by famous European architects during 19^{th} and 20^{th} century. By the beginning of 19^{th} century, the state of the city changed, as the aristocracy, rich and the elite deserted it westwards into the new extension to the city. Such demographic modification adversely affected the social structure, as many of the buildings were re-occupied by secondary traders and laborers. Otherwise most buildings were converting into industrial workshops. All that had a reverse effect not only on the historic fabric but also on the structural safety of these buildings. The work that composes the subject focuses on three main issues. The first issue builds on both in-situ survey and on an extensive literature review to study renaissance structures in Cairo. Where, the second issue is to identify and briefly describe the structural and architectural damage caused to historic renaissance buildings due to many cases such as, the misuse, the effect of 2011revolution, Cairo Metro railway Practices (project 2017: 2020) and change and conversion processes. The last issue is to propose adequate intervention and retrofit procedures to strengthening and repair damaged structures or to upgrade undamaged ones.

Keywords: Conflict, Damage assessment, Intervention methods, Misuse, Modernity, Renaissance structures, Strengthening, Structural damage.

Introduction

Whether you are in a town, district, alley, or even in the country you are certainly not away from one of Egyptian's historic structures. Cairo is an urban historic city that expands from street to alley to lane (ICOMOS, 1979; UNESCO, 2012). Historically, Cairo was initiated on the eastern side of the Nile River banks as shown in Figure 1 (Sykora et al., 2009; Hawas, 2002; Abdelmegeed, 2015). Nearly all these areas, which are set with red square in Figure 1, are founded by the beginning of 17th century and end of 19th century.

Figure 1. *Cairo Map*



Source: https://www.lonelyplanet.com/maps/africa/egypt/cairo.

In 19th century the demographic image of Cairo state began heavily transformed, in particular its residential urban fabric. Renaissance structures considerably have significant distinctions in construction methods, building materials, architectural components and decorative elements. Renaissance architecture in Cairo is considered to represent the artifacts, structural and architectural trends predominating in Egypt and Europe this period (Baroque, Rococo and gothic style) as shown in Figure 2.

By the late of 18th century the urbanism in Cairo began to desert to westernization, particularly under the reigns of Mohamed Ali and his successors (Abou El-Ela, 2003; Hawas, 2002; Rabbat, 2011). During the Ismailia period (Khedive Ismail 1830-1895), one observes the drift towards ignoring Arabian traditional behavioral aspects, as in this model, entrances were followed by a lobby or a doorway then a hall for the purpose of the partitioning of spaces (as influence of European architecture) (Abdel-moniem, 2010, 24; Ficarelli, 2009; Abdelmegeed, 2015).

Figure 2. *Examples of Renaissance Structures in Cairo (ElSakakini Palace and Building 35 in Bostan St.)*

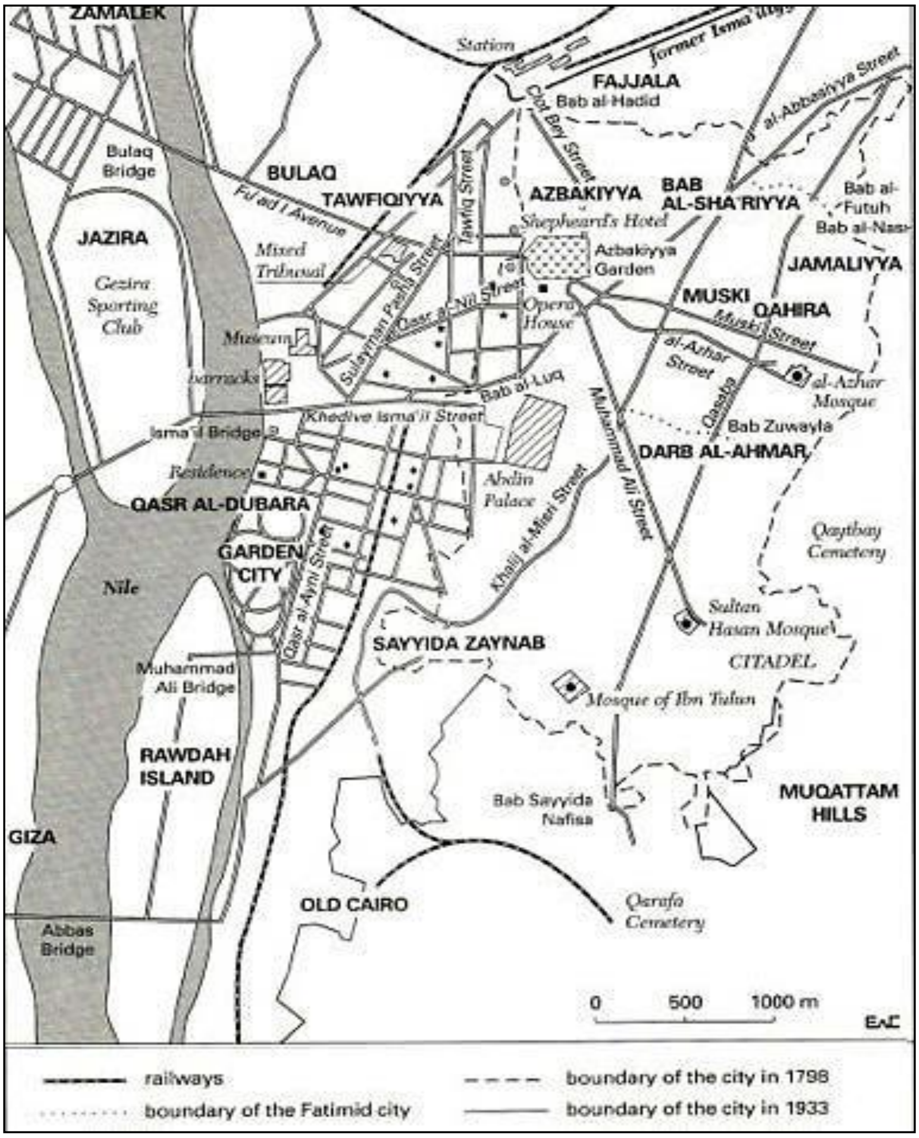
In situ observations to renaissance heritage structures visited, as a whole, are in bad condition and are not sufficient protected against surrounding hazards. 60 percent of the inhabitant buildings were either in bad condition, or in need of total restoration. Otherwise, the buildings that were maintained until the second half of the 20th century were exposed to rapid deterioration of masonry and wooden ceilings due to the effect of misused and environmental factors. As sequences of neglect and ignoring to the heritage values of renaissance structures a lot of palaces were re-placed with rental flats, other buildings were used indiscriminately for unsuitable functions. Furthermore, the buildings suffered from a lack of necessary maintenance or even official attention of those responsible for these buildings (Hawas, 2002; Abdelmegeed, 2015, Elyamani et al., 2018).

Most previous researches which discussed the renaissance architecture in Cairo/Egypt, for example Hawas, 2002, Abdelrady et al., 2010; Elyamani et al., 2018; Michele Betti et al., 2010; Hemeda, 2013; Rashad, 2015; Abdelmegeed, 2015, etc., focused in the effect of environmental factors and the misuse on these buildings. But this paper will concern with another issue depending on the structural and architectural damage phenomena and the methods used to retrofit and rehabilitate renaissance buildings in Cairo. The main objectives of the work are on one hand, to present brief description to renaissance structures in Egypt and on the other hand to determine and evaluate the extent and types of structural and architectural damage sustained by heritage renaissance buildings. This determination mainly depended on the evaluation of current situation through in-situ observations, and documentation of recent and present restoration works.

Description of Renaissance Structures in Egypt

In Mohamed Ali region (1805) Egypt testified its first days of being modernized where first urban expanding outside the Old Cairo (Islamic Cairo) boundaries were started in his region period (see Figure 4). The most significant changes in Cairo urban development during the rule of Mohamed Ali and his successors are (a) straightening and improvement the streets of Old/Islamic Cairo, (b) relocation of old cemeteries, (c) the creation of monumental plaza and some regular divisions and (d) filling the ponds and swamps adjacent to Old Cairo and leveling its lands (Hawas, 2002; Rashad, 2015; Abdelmegeed, 2015; Regina Santos, 2018).

Figure 3. *Transformations Happened in Cairo during Mohamed Ali and Khedive Ismail Periods*



Source: Rashad, 2015.

Renaissance structures in Cairo designed in the form of traditional masonry architectures as all of 19th buildings constructed using local natural stone or of fired clay bricks. It is also one of the most versatile, in terms of structural form, consists of bearing walls, arches, pillars, domes and vaults. The majority of renaissance buildings were planned and designed by European architects who arrived in Egypt in khedive Mohamed Ali and his successors (1805) rule, in particular Khedive Ismail and Khedive Said rule era (see Figure 4).

Figure 4. *Examples of 19th Century Structures in Cairo (in Opera Square)*

On one hand the first quarter of 19th century structures were characterized by a re-reading of models of classicism from the latter part of the 18th century or Napoleonic era "*ancient Greek or Roman principles and style in art and literature*". On the other hand, the European architects who arrived after (1848) began to show the first signs of retrieval - with a selective attitude and exempt of philological preoccupations, stylistic forms and ornamental drawn from the collections or repertoire of Islamic architecture (Harris and Giovanni, 2004; Oram and Stelfox, 2004; Mohamed, 2009; Hemeda, 2013; Elyamani et al., 2018). European professional architects and artists, in particular Italians such as Avoscani, Lukovitch and Francesco Mancini became progressively involved also with private and community developments in the westernization of 19th century architecture. Otherwise, Westernization action was not confined to Cairo alone, but it included most of Egyptian governorates. In general this happened when new urban notable elite and the earliest wealthy Greek families (Zizinia, Tossiza, and D'Anastasi) tried to express their readiness to sponsor their private living and ethnic communities (see Figure 5)

Figure 5. *Examples of 19th Century Palaces in Zizinia District-Alexandria*

For the Tossiza Palace, the most prominent building on the square (today become the Stock Exchange/*La Bourse*), Mancini continued using his concepts, expressing his best architecture in Neo-c1assical language Following the same tradition were his compatriots, Luigi Storari in the Greek Church, *Evangelismos* 1847-1856, and Ernesto Bierotti's developments of the Greek community residential buildings in 1853 (Awad, 2008; Mohamed, 2009). As general role, when looking to renaissance buildings in Cairo, we will find that the level of development of the structural system depends on the following factors

- The size of the buildings varies from one to the other depending on its use (church, palace or residential house). Thus, plan dimensions varying from some meters to some tenths of meters.
- Buildings have slightly rectangular or square in-plan geometry, with two, three, four or even 6 floors at most.
- The separation distance between buildings varying from 3: 6 meters and more as a rule when separated from adjacent buildings. The separation distance mostly depending on the buildings typology. In spite of we find that the separation distance between buildings does not exceed 4 meters in some district, we find that the distance between palaces and adjacent buildings not less than six meters at least (see Figure 6).

Figure 6. *Separation Distance between Different Types of Buildings*

- One of the most unique characters of renaissance structures in Egypt is the use of preceding arcade system with fanlight doors.
- The estimated opening area to the total wall surface is approximately 23%. The high ratio of openings intentionally for ventilation purpose. The main function of building is for more than one family. It is very common to find these buildings used for commercial purposes.
- The lateral load-resisting system is un-reinforced masonry walls. The main lateral load-resisting system consists of unreinforced stone masonry bearing walls. Floors and roof are wooden structures. The wall layout in plan is critical for the lateral performance of this construction type. Also, the connection between the structural bearing walls was effected through the use of large limestone blocks (corner stone's).
- Renaissance structures in Cairo built by using local building materials in the shape of blocks (natural stones) or manufactured shape (fired bricks) and a series of mortar joints arranged irregularly (as in stone masonry) or regularly (as in brickwork) (Lopez et al., 1998; Abdelmegeed, 2005). The most building materials used in 19th century buildings are rubble (cobble) and ashlars stones in addition to fired bricks in certain partitions of the building. The structural load-bearing walls are constructed in the form of the single-leaf or of the so-called three-leaf type (with two discrete external leafs and an infill material‖), with varying thicknesses (less or more than 600 mm) as shown in Figure 7.

Figure 7. *Load Bearing Walls where (A) Single-leaf Type and (B) Three-leaf Type*

- Timber floor construction in the form of wooden beams covered with wooden planks, ballast fill, and tile flooring, as shown in Figure 8. Sand or straw overlay is provided in between planks and boards of the roof for thermal comfort. In most cases, timber joists are placed on top of walls without any positive connection (see Figure 8).

Figure 8. *El-Gohara Palace Roof (Using Sand Overlay under Wooden Planks)*

- Roof/floor timber pegged together by using nails and screw fixings. On one hand 99% of roofs in renaissance buildings in Cairo were constructed in the form of flat roof but approximately 5% of them were covered with the so-called wooden pergola. On the other hand, during in-situ survey to demolished building which dates back to the first quarter of 20th century (Figure 9) it founded that they used iron bars instead of wooden beams. The iron bars were covered with wooden planks.

Figure 9. *The Use of Iron Bars in Renaissance Structures (Elmonera District House 1940:1945)*

Structural Damage Factors and Deterioration Aspects

The essence of damage mechanisms in structures is the outcome of the interaction between the structure and the surrounding environmental actions; in fact, the persistent or continuous changes of the surrounding environmental actions play an important role in the deterioration of historic masonry buildings (Sharma and Maitis 1995, 12; Dov, 2004, Caliò et al., 2014; Abdelmegeed, 2005). Otherwise, Valluzzi, et al. 2005 and ICOMOS 2003 referred that structural and architectural damage in historic buildings occurs when the external forces stresses increase beyond the strength of the building materials at locations of the structural elements parts.

Also, some of historical buildings underwent to some modifications processes, in particular the decrease of the building's height, the elimination of a monumental portal or gate, and replaced the original wooden roof by terraces with concrete slabs and concrete beams. However, these structural modifications lead to significant deterioration phenomena (Figure 10).

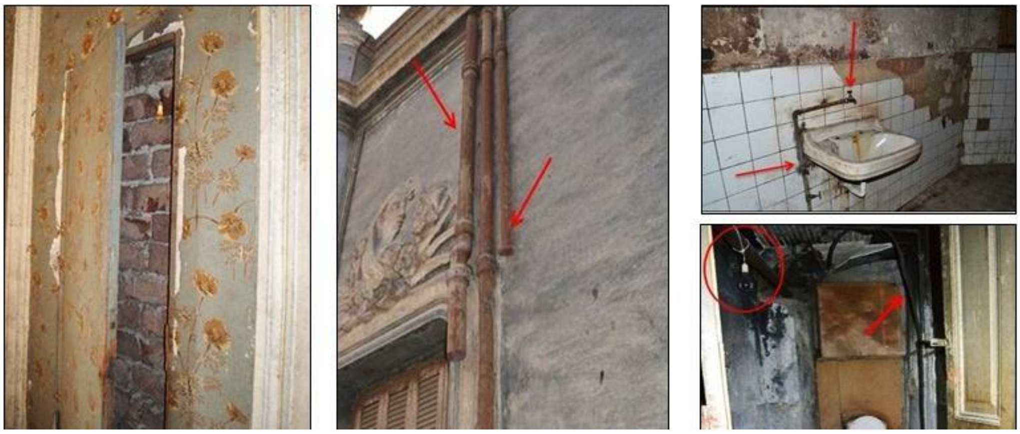
Figure 10. *Structural and Architectural Damage Aspects in Renaissance Buildings in Cairo*

As mentioned before the paper will address the impact of man-made and modernization actions which have a significant deterioration mechanisms on renaissance structures. Accordingly, we will study the effect of **a**) change and conversion, **b**) 25 January 2011 revolution effect (conflict effect), and **c**) the effect of Cairo Metro railway Project (project 2017: 2020).

Change and Conversion

Change and conversion, in historical buildings, are most likely to occur due to change in use of the buildings or due to added or removed one or more of architectural elements or even added additional floor upon the building. Renaissance structures in Cairo usually have undergone many significant deterioration phenomena due to substantial changes in its structural and architectural system, including partial demolition, removal of internal walls, added new openings (door and window openings), for example in El-Sakakini palace when El-Sakakini family gave the owner right to the Ministry of Health for some years, the palace was misused and neglected and certainly the Ministry of Health was not the best caretaker of the palace. Ministry of Health mad some substantial changes in the architectural system of the palace such as making a new door and window openings, a new lighting and electrical supply elements, and a new plumbing system (see Figure 11).

Figure 11. *Substantial Changes in the Architectural System of EL-Sakakini Palace 1879*



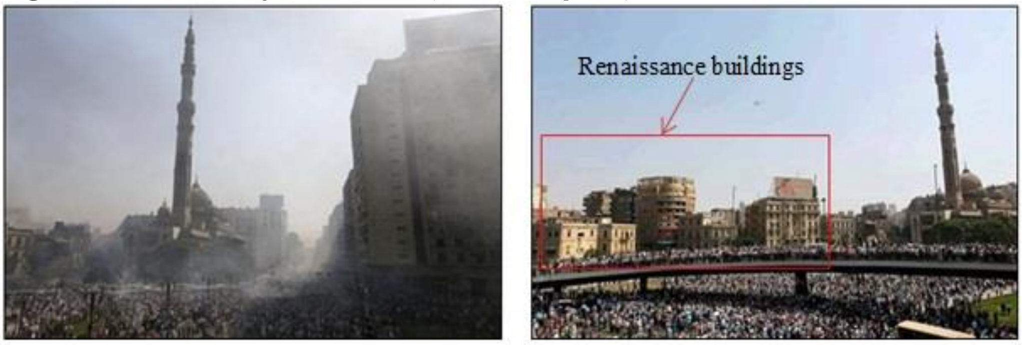
Recently, palaces and larger renaissance houses were abandoned into smaller and higher concrete structures. A lot of heritage buildings were re-placed with rental flats, other buildings were used indiscriminately for deferent, mostly unsuitable functions. Otherwise, renaissance buildings in Egypt usually undergo to modification processes. Modification actions take many shapes such as the decrease in height of an entire story, stripped off some of original portals and increment extra floors to the building (Figure 12) and as a result of such modifications the buildings susceptible to serious architectural and structural damage phenomena such as, cracking, settlement, failure in localized regions, building collapse and adversely affect historic character (Abdelmegeed, 2015; Caliò et al., 2014).

Figure 12. *New Extra Floors in Renaissance Buildings*

Conflict (2011 Revolution)

In the first quarter of 21th century (starting from 2010) Cultural heritage in Middle East suffered a new category of deterioration factor named (Arabic spring). In January 2011, public revolution began in Egypt this revolution has their destructive impact not only on income resources or people’s lives but also on cultural heritage (Figure 13). Increasingly, conflicts target symbols of culture to destroy identities and lead to the deliberate destruction of cultural heritage – but this damage can also be accidental. In terms of specifically cultural properties, 2011 and other revolutions or conflicts in Egypt impose different types of damage to cultural heritage in Cairo.

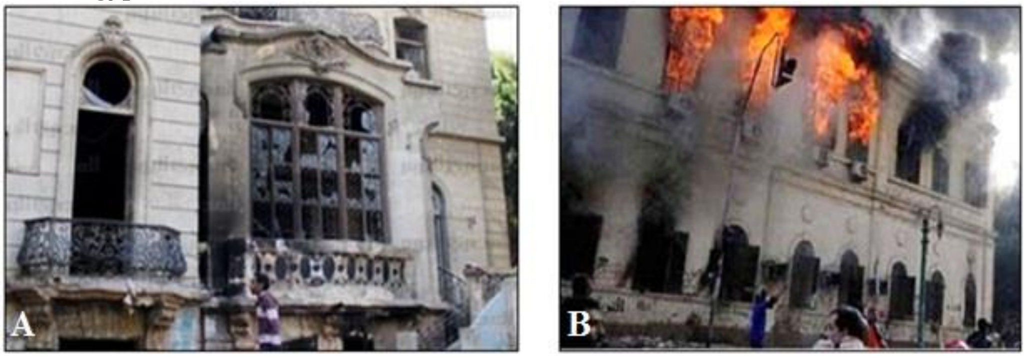
Figure 13. *25 January Revolution (Ramses Square)*



The negative affected of 25 January revolution on renaissance buildings in Egypt can be summarized as the followings:

1. Intentional targeting by hostile groups intending to devastate the racial, national or religious symbols of countries or to impose specific intruder ideologies. Otherwise, the effect of the political fights and instability in the country during 2011 and 2012 was clear on the deteriorations and destructions of some historic renaissance buildings in downtown Cairo, as shown in Figure 14.

Figure 14. *Damage Phenomena during the Following Events of 25th January Revolution where* (A) *French School Lycée la Liberté de Bab El- Louqe* (B) *Fire in the Egyptian Science Institute*



2. The vast majority of renaissance structures follow the individual private ownerships and the owner made their efforts (Exploited of security absence after 25 January revolution) to destruct these buildings (see Figure 15) and rebuilt them in the form of high steel buildings searching of rich
3. Unintentional destruction due to both of the neglect of the value of historic buildings and the absence of governmental role. As a result of neglect the people who lived adjacent to the uninhabited buildings use them as garbage dump.

Figure 15. *Destructing Processes to Renaissance Building during the Following Events of 25th January Revolution*

Effect of Underground Metro

The khedival Cairo Area, downtown, is considering the biggest and most densely populated place in Greater Cairo. On one hand Metro is strongly concept for enhancing the living standard in khedival Cairo Area and on the other hand Cairo Metro Line 3 presently operates from *Attaba* to *Ahram* station in Heliopolis region, crossing khedival Cairo Area (downtown). The total length of the line will be approximately 50 kilometers (31 miles), most of the total length is in bored tunnel. Figure 16 shows the Metro lines destinations and the historic area in Cairo (Ministry of Transportation, Metro sector, Egypt, 2015).

Nowadays renaissance structures in khedival Cairo are suffering many deterioration phenomena due to the effect of Cairo Metro Line 3 project. As shown in Figure 17 the project crosses under 23 July Street which has many of renaissance buildings. Vibrations generated by the project running on underground tracks transfer through the ground into surrounding structures. These induced vibrations usually cause no threat to the safety of the structures, but their undesirable impacts can significantly lower the quality of life and the working conditions of these structures. Also there may be concern about the possibility of adverse long-term effects of vibrations on old buildings and historical monuments along metro corridors, especially those in a weak condition (Ziad Nakat, 2014; Twinning Project Fiche, 2015). Many historical buildings located in El-Gaaish Street, including dwellings and shops were damaged due to suddenly ground settlement during digging the metro tunnels.

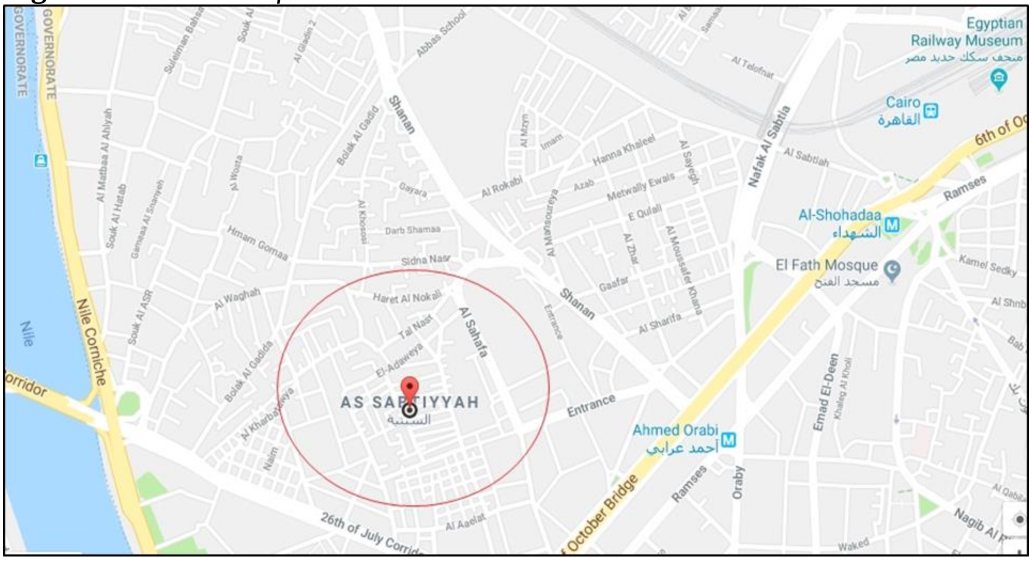
Figure 16. *Egyptian Metro Railways (Twinning Project Fiche 2015)*

Figure 17. *Metro Tunnel Digging Operations Adjacent to Renaissance Buildings (Downtown)*

Case Study (*SABTIIYYAH* Building)

SABTIIYYAH is one of the old historical neighborhood districts of khedival Cairo, clustered around the famous Ramses square and Ramses Railway station (Figure 18). *SABTIIYYAH*, the Egyptian historical district, contains a large number of historical, economical, architectural and traditional masonry buildings.

Figure 18. *Location of SABTIIYYAH Districts*



In the middle of *SABTIIYYAH*, to the north west of Ramses square , where the building that forms the subject of the case study is located and will be referred to as “*SABTIIYYAH* “ building, thereafter (Figure 19). *SABTIIYYAH* building, which was built in the late 19th - early 20th century, is one of renaissance buildings which represent the architectural and structural trends widespread in Cairo this period. By time, this house has suffered significant structural and architectural damage phenomena due to various causes, such as construction defects, seismic excitation, neglect, environmental surrounding factors etc.

Figure 19. *SABTIIYYAH Building*

Limestone, semi-chiseled and chiseled stones, are the main building materials used for *SABTIIYYAH* building the construction of structural and architectural elements (see Figure 20). While Mortar (gypsum mortar), containing a major quantity of sand and a smaller quantity of gypsum.

Figure 20. *Typical Semi-chiseled and Chiseled Stones*

The structural walls in the building have a width of 0.4 m. They were built with semi-chiseled limestone, bound together with large amount mortar "ashlars masonry". The roof of the building (completely destroyed) was made of, 15 m high x, 11 m wide timber beams arranged in parallel at unequal distances of 50 to 70 cm. Timber beams covered with 35 cm wide x 4 cm thick planks as shown in Figure 21. The beams are simply supported within recesses formed in opposite walls.

Figure 21. *Timber Beams and Wooden Planks in the Roof of SABTIIYYAH Building*

Current Situation

From visual observation, it has been settled that the building suffer significant structural damage in its masonry walls and roof. Structural damage such as collapse of roof, out-of-plane displacements, loss of mass, wall deep cracking, destroyed of internal and external walls, etc. The damage suffered as a result of aging, construction faults/ defects, lack of maintenance, environmental actions, neglect and willingness of building owner to demolish it in order to rebuild in the form of high concrete building searching of wealth.

On the other hand the building suffers a localization collapse in its internal and external walls in addition to a whole roof collapse (see Figure 22a and 22b). Wall collapse is due to structural defects (inadequate design) and the use of unsuitable building materials.

Figure 22. *Structural Damage Phenomena where* (a) *Failure in Localized Regions and* (b) *Roof Collapse*

Damage Assessment

Damage assessment/identification is aimed at assessing the current situation and condition of an existing structure; there is equal in medicine field: any successful treatment must be preceded by a proper diagnosis. In appraisal, the restorer is left face to face with an existing structure of definable qualities and must determine its condition and suitability of use (ICOMOS, 2003).

Documentation

The assessment of the building materials used in the *SABTIIYYAH* building is based on visual observation, sampling of building materials and the laboratory testing of the samples (X Ray Diffraction (XRD) and chemical composition of mortar used).

Mineralogical characteristics to limestone were determined by using XRD analysis application, (Siemens D-5000 X-Ray Diffractometer (XRD), with nickel-filtered Cu $K\alpha 1$ radiation). Otherwise Mortar specimens were taken and prepared for the chemical analyses. From in-situ sampling the mortar was found very fragile and friable due to the effect of surrounding deterioration factors. Table 1 shows the results of the chemical analysis of the mortar used in the construction of the targeted building.

Table 1. *Results of Chemical Analysis (% w.w) of the Render Samples*

Chemical composition	**CaO**	**Na_2O**	**MgO**	**Cl**	**Fe_2o_3**	**SiO_2**	**So_3**	**L.O.I**
w.w%	51.23	3.88	2.52	1.75	1.20	2.98	0.65	**35.2**

On the other hand, Figures 23 and 24 presented X-Ray Diffraction patterns of limestone samples which were collected not only from collapsed walls but also samples from non-collapsed ones. X-ray diffraction patterns of limestone samples showed the presence of Calcite carbonate ($CaCO_3$), the main composite of limestone, Halite NaCl in minor phase and Quartz (SiO_2) in traces phase. The mortar used in the construction of *SABTIIYYAH* building in bad condition, it suffer notable damage phenomena due to internal and external damage factors. Chemical analysis was used in order to assist the mineralogical characterization and to assume whether or not a lime-gypsum mortar was used for the masonry construction. Table 1 presented the chemical composition of the mortar used in the building.

Figure 23. *XRD Patterns of Limestone Specimen No. 1 (from Collapsed Parts)*

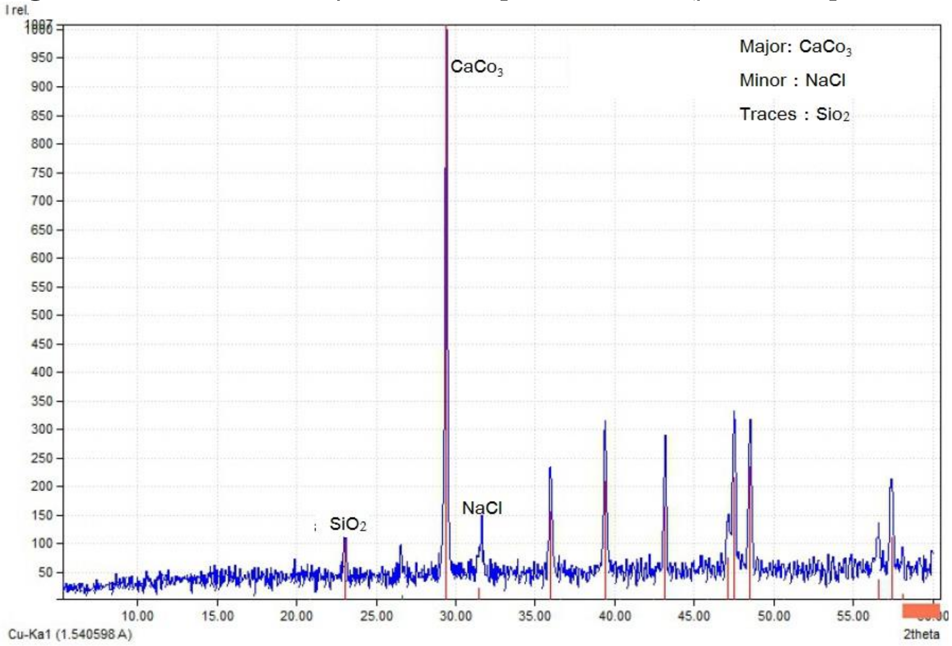
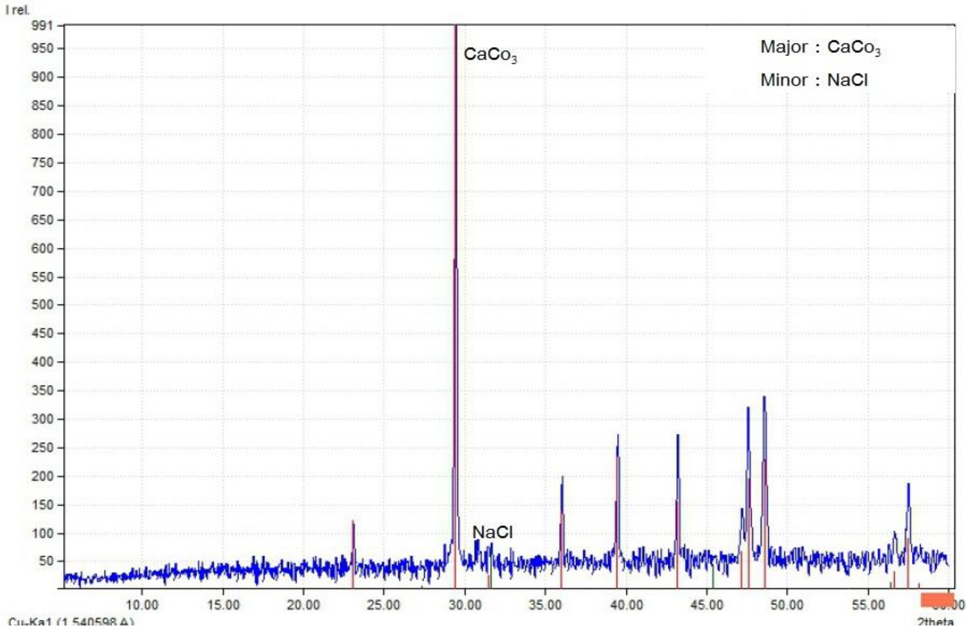


Figure 24. *XRD Patterns of Limestone Specimen No. 2 (from Non-Collapsed Walls)*



In addition to the mineralogical characteristics to limestone, Fitzner et al. (2002) had classified in their study the porosity prosperities of Egyptian limestone used in construction of historical buildings and in restoration processes of heritage buildings. Table 2 presents the values of porosity of limestone quarry from Mokattam Mountain, Helwan and Giza plateau quarries.

Table 2. *The Porosity Prosperities of Egyptian Limestone Used in Construction of Historical Buildings and in Restoration Processes of Heritage Buildings where, M Mokattam Quarries, H Helwan quarries and G Giza Plateau Quarries (Fitzner et al., 2002)*

Litotype	**Total porosity (Vol-%)**	**Porosity (in pore radius classes) (Vol-%) 0.1 µm:10 µm**	**10 µm:1000 µm**	**Median radi of pore entire (µm)**	**Pore surface $m^2.g^{-1}$ / $m^2.cm^{-3}$**
M 1	18.60	14.00	3.10	0.70	1.80/4.0
M 2	20.00	12.50	6.50	0.90	1.0/2.20
M 3	25.30	6.40	18.00	1.10	1.40/2.70
M 4	26.80	19.50	5.60	0.70	2.90/5.90
H 1	8.50	6.50	0.30	0.10	1.80/4.50
H 2	37.40	28.10	4.20	0.80	7.20/12.30
G 1	18.60	8.90	1.40	0,30	1.90/4.50
G 2	19.20	8.20	10.20	1.10	0.80/1.70
G 3	28.80	20.80	2.00	0.50	3.30/6.80
G 4	25.60	13.40	10.00	0.50	2.40/5.00

Results Discussion

From tests results obtained, deterioration phenomena and in situ survey to *SABTIIYYAH* building and other renaissance structures in Cairo, it concluded that most of renaissance structures, in particular dwellings, suffered slight to high damage levels. Some of these buildings suffered large cracks, building materials detachment, loss of some architectural and decoration elements, whereas the other buildings, such as palaces and old Villas, reached partial or total collapse. Structural deficiencies, the harm of environmental surrounding actions, modernity factors in addition to the absence of legal protection are the causes and reasons lead renaissance structures to being continuously display to significant damage phenomena.

Otherwise, many renaissance heritage buildings in Great Cairo area are seriously threatened by significant damage factors (as mentioned before) and they are in need of intervention to protect Carine renaissance buildings from loss. Structured studies were carried out for diagnostic characterization of damaged renaissance structures in Cairo and for determine their structural and architectural damage phenomena. *SABTIIYYAH* building, a house date back to the late of 19th century, is the case study building. The methodology followed to study the structural and architectural damage in the building comprised laboratory tests and in situ investigation where, the later including in detail survey of deterioration forms, registration and documentation of deterioration phenomena. From building materials tests as shown in Figures 23, 24 and Tables 1 and 2 we can conclude that the building materials suffer of salt weathering due to the effect of surrounding environmental actions. Otherwise the effect of salt weathering on limestone is limited because of *SABTIIYYAH* district is far from the effect of groundwater (The soil level is higher than the ground water level). On the other hand the harmful of deterioration factors beside the poor composition of the mortar are the main factors lead to mortar loss and bleeding leaving stone courses without bending mortar.

Following to the description of deterioration factors and deterioration phenomena in Carine renaissance structures with the application on *SABTIIYYAH* building and according to the research methodology, the paper will discuss and study some proposed intervention methods that can used to upgrade and strengthening renaissance buildings in Cairo, Egypt.

Proposed Interventions to Strengthening Renaissance Structures

The basic concept of any proposed interventions to historical building is to improve its durability without changing its historic, decorative and aesthetic fabric (where possible). So, the goal of interventions in historical buildings is not to change the historic and architectural character (conserve the building as original as possible), but also given the opportunity to prepare it for a new use, if possible. If replacement is urgent, materials similar, preferably identical, to the original ones should be used. Each property should be recognized as a physical record of its time, place and use (ICOMOS, 2003; Beckman and Bowles, 2004; Magenes, 2006; Rashadul, 2008).

The totally comprehensive summary of structural and architectural damage presented in the prior section, on different kinds of renaissance building structures, was intended to illustrate not only the vulnerability of renaissance buildings with its specific culture and traditions but also the harmful attack of new categories of deterioration phenomena on renaissance structures in Cairo region. The following questions are the important inquiries emerged from the study: (a) what can be done to reduce the vulnerability of existing damaged or undamaged buildings and (b) what is the compatibility intervention methods used to retrofit and strengthen the structural behavior of renaissance buildings without changing their historic, decorative and aesthetic fabric. From structural and historical point of view, the following proposed methods can be used to repair and retrofit renaissance buildings in Cairo.

Injection

All unintended voids or gaps in masonry are usually referred to as “cracks”. Injection is the most proper used methods to repair cracks and diffuse voids in the inner part of the walls. Injection increases the durability of the masonry building materials and hence improves its physical and mechanical properties. Injection technique is based on the injection (in holes with injection tubes and spread throughout walls), of grout to the internal cracks. For the external cracks the coating should be removed previously and the injection tubes may also be used. Injection grout should be a composition as near as practicable to the original (Rashadul, 2008; Miguel and Luis, 2001, Beckman and Bowles, 2004; Abdelmegeed, 2015).

Stitching

Stitching usually, aims on one hand to improve the mechanical characteristics of the masonry walls without visible modification. On the other hand it also improves the connection of the two layers of the rubble-cored wall preventing their separation from the interior rubble core.

Steel bars to be long enough to extend a minimum of 50cm either side of the crack or 50cm beyond the outer cracks if two or more adjacent cracks are being stitched using one rod. If there is render, this thickness must be added to the depth of slot. Crack stitching must be installed in the masonry and never in the render.

A possible safeguard against this would be to incorporate temporary injection nozzles into the mortar joints to allow grouting of the space behind the stone after the mortar has set (Sayed Ahmed and Shrive, 1998; Beckman and Bowles, 2004). Otherwise the use of steel bars technique (as shown in Figure 25) causes damage due to the corrosion process to these bars leading to cracks in walls. So if necessary we must use the stainless steel bares or use steel bars fixed inside the PVC tubes to easy remove or maintain the corrosion steel and avoid the direct contact between the steel bars and the masonry.

Figure 25. *Stitching Techniques Used in Strengthening Masonry Buildings*

Fiber-Reinforced Polymer (FRP)

The last two decades of twentieth century have seen the create of composite materials (fiber reinforced polymer or FRP composites) for the strengthening of existing structures (Nanni, 1997; Mayorka and Meguro, 2008; Rashadul, 2008; Nanni, 2012; Augenti et al., 2013; Abdelmegeed, 2015) European countries, in particular Italy has been at the vanguard in the use of the Fiber-Reinforced Polymer (FRP) technology from the practical point of view as well as retrofitting of historical buildings (Augenti et al., 2013). FRP applications include externally bonded fiber plates/sheets installed and adhesively bonded to masonry architectural elements. FRP can install both manually by means manual lay-up and pultruded FRP sheets, adhesively bonded. The first method can produce shear and flexural strengthening to masonry elements besides column confinement (Figure 26a), whereas the last mentioned method is primarily used for flexural strengthening (Figure 26b) (Mayorka and Meguro 2008, Augenti et al., 2012; Nanni, 2012; Augenti et al., 2013).

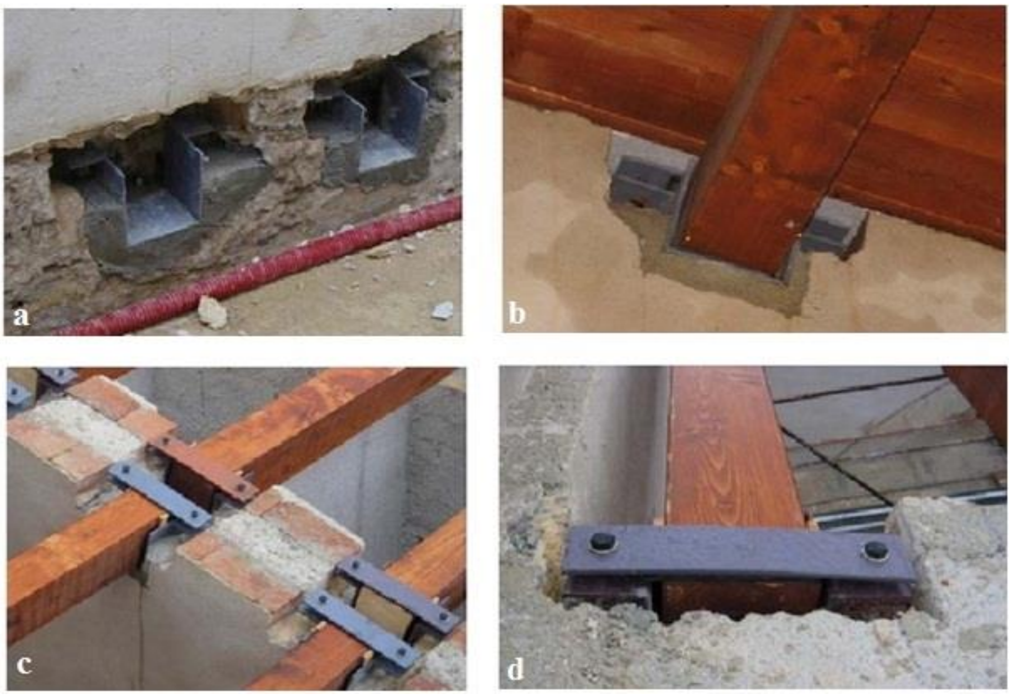
Figure 26. *Installation Techniques of Fiber-reinforced Polymer (FRP):* (a) *Manual Lay-up of FRP (Column Confinement)* (b) *Bonded Plate for Flexural Upgrade* (c) *Individual Bar in Jointed Mortar* (d) *Plate/Sheet Pre-tensioning System (Augenti et al., 2013)*

Furthermore, composite materials such as Carbon or Glass- Fibers Reinforced Polymers can use to strengthen masonry buildings with, piers and spandrels within masonry walls and/or columns. Carbon Fiber-Reinforced Polymer (CFRPs) or Glass-Fiber Reinforced Polymers (GFRPs) are glued with epoxy resin to the pre-cleaned surface of masonry elements. The weak element is the masonry or the glued surface if the biding is not well done. Connectors can be placed, especially on walls, so that the strengthening material is totally bonded to the masonry. This method is easily applicable in terms of low cost upgrading of masonry structures to limit damage caused by earthquakes (Mayorka and Meguro, 2008; Rashadul, 2008).

Roof Reconstruction and Strengthening

In old and historical buildings it is essential to conserve and strengthening its floor wooden elements. Floor wooden beams and boards should only be replaced just in case of restoration processes are impossible. Replacement timber elements should match the existing one both in species and in technique of conversion, which will permit the quality and grain also to match. Floorboards should be re-fixed in their original positions with nails, taking into account not to hole or puncture underlying electrical cables. In the case of replacing the wooden boards or wooden beams in historical structures by new one it is recommended to insert the wooden beams into the bearing masonry walls throw stainless-steel or FRP cases with stainless-steel plate and plots at the top of the walls (Figure 27).

Figure 27. *Floor Wooden Elements where* (a) *the Steel Cases into the Wall* (b) *Wooden Beams Inside the Case* (c and d) *the Connection Technique between Walls to Steel Cases and Steel Cases to Wooden Beams*



This technique is necessary not only to make strong connection between beams and walls but also to avoid the out of plan failure. Also cases transforming the loads from beams to wall. Otherwise, wall-inserted cases help in reversible the action as it will be easy to restore or replace the beams when needed (Mayorka and Meguro, 2008; Rashadul, 2008; Mohamed, 2009).

Furthermore, many of previous restoration works recommended to use carbon fiber reinforced polymers (CFRPs) to reinforcement of dome roofs in historical buildings (Meli and Sancez-Ramirez, 2007; Casadei and Angeloni, 2007; Casarin and Modena, 2008; Rashadul, 2008, Portioli et al., 2010). CFRPs will enhancement the tensile resistance of the roofs, in particular dome one and minimizing the risk of cracking. It is an effectual technique which has been successfully utilized and applied in many historical places nearby like: Mustafa Pasha Mosque in Skopje, St. Helen and Constantine church in Piraeus, Consulta Palace in Rome etc. (Casadei and Angeloni, 2007; Portioli et al., 2010; Augenti et al., 2013).

Conclusions

The 2011 revolution in Egypt and its subsequent events have highlighted the vulnerability of heritage structures to sustain such new deterioration factors. All renaissance structures in Egypt, whether they are large or small, complex or simple structures present a contribution to the quality of our life by informing us of the lives and achievements of our predecessors. Yet with the early of 19th century modernity processes in the state of Cairo changed, as the aristocracy, rich and the elite deserted it westwards into the new extension to the city. Such demographic modification in this period adversely affected the social structure, as many of the buildings were re-occupied by secondary traders and laborers. Otherwise most buildings were converting into industrial workshops. All that had a reverse effect not only on the historic fabric but also on the structural safety of these buildings

Renaissance buildings in Cairo suffered minor to heavy damage, such structures had the following deterioration categories: (a) 60 percent approximately of the inhabitant buildings were either in bad condition, or in need of total restoration; (b) the buildings were maintained until the second half of the twentieth century were exposed to rapid deterioration of masonry and wooden ceilings due to the effect of misused and environmental factors; (c) as sequences of neglect and ignoring lots of palaces were demolished and re-built with huge concrete buildings, other buildings were used indiscriminately for unsuitable functions.

Change and conversion, in renaissance buildings, are most likely to occur, on one hand due to change in use, added or removed one or more of architectural and decoration elements or even added additional floor upon the building, on the other hand due to the absence of legal protection for these buildings. Renaissance heritage in Egypt has the majority portion of the adversely affected of 25 January 2011 revolution. The conflict events and instability during 2011 and 2012 resulted in deteriorations and destructions to some historic renaissance buildings in downtown Cairo. Furthermore, renaissance buildings in khedival Cairo nowadays, are suffering many deterioration phenomena due to the effect of Cairo Metro project (Line 3, 2017:2020). Vibrations generated by metro train running on underground tracks transfer through the ground into surrounding structures. The undesirable impacts of such projects can significantly lower the quality of life and the working conditions of these structures, especially those in a weak condition.

From the visual inspection, laboratory tests and the assessment results to the case study building (*SABTIIYYAH building)*, it was observed that the renaissance structures in Cairo exhibit structural and architectural deterioration phenomena. The most common phenomena are: detachment of surface plaster, loss of masonry units, non-structural and structural cracks, localized collapse, damaged roofing, bad and insufficient drainage systems, modernization phenomena (bad instillation of air-condition equipment, change the original marble stairs with concrete one etc.).

The basic principle of the proposed interventions to rehabilitate the renaissance structures is to improve its static and seismic behavior without changing its historic and aesthetic fabric (where possible). Injection, transversal anchorage in walls "Stitching", Fiber-Reinforced Polymer (FRP) and roof reconstruction and strengthening aims to improved mechanical characteristics and to improve its static and seismic behavior with minor changing in its construction fabric.

One of the most common phenomena in renaissance architecture in Cairo is replaced the original wooden roof or even wooden beams in historical buildings by new one. In this case, only if the restoration processes are impossible, it's preferable to introduce the new beams into the bearing walls throw stainless-steel cases with stainless-steel plate and plots at the top of the masonry walls. This technique is necessary (a) make strong connection between new wooden beams and masonry walls to avoid the out of plan failure; (b) stainless-steel case transforming the loads from wooden beams to masonry wall; (c) stainless-steel case helps in reversible the process as it will be easy to treatment or replace the beams when needed.

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