International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 04 | Apr-2016 www.irjet.net p-ISSN: 2395-0072

A Review on Repair and Rehabilitation of Heritage Buildings

S. Raja Subramaniam

ME Final year (Construction Engineering and Management) - Meenakshi Sundararajan Engineering College, Chennai-24. India

---

Abstract - *Information regarding this paper discusses the Review of Repair and Rehabilitation of Heritage Buildings. In current scenario of Building Research, Repair and Rehabilitation plays a vital role as it serves important in building applications. It acts as an inevitable solution in maintaining the Integrity of Structures, in case of Heritage structures. Repair and Rehabilitation of heritage buildings has become a concern of greater importance over the world, notably in the developed countries. The major defects reported are discussed and a suitable and economical solution for a particular defect is identified by a tradeoff between cost, lifetime and adaptability of the solution.*

Key Words: **Heritage, Repair, Rehabilitation, Heritage Buildings, Cost, Lifetime, Adaptability.**

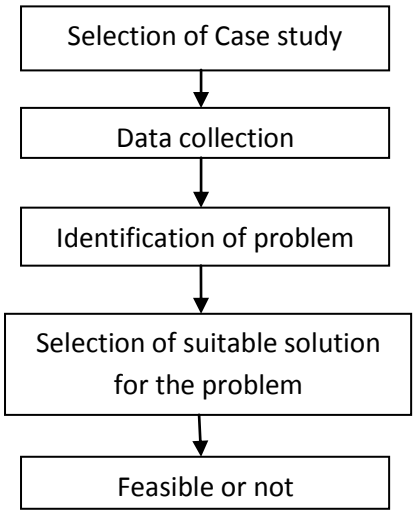
1. INTRODUCTION

Repair and Rehabilitation is an Art of Civil Engineering work which enables to extend the service life of a structure. Repair and Rehabilitation is defined as the process of achieving the original state of structure when it undergoes any sort of defects or deterioration or destruction. Restoration of structure is an ultimate aim of Repair and Rehabilitation where it plays a major role by maximizing the functional utility of the structure.

Repair and Rehabilitation technique is also used to modify a structure to meet new functional and other requirements. Many structures may need Repair and Rehabilitation for one of the following reasons

1. Deterioration due to Environment effect.
2. New functional or loading requirements entering modifications to a structure.
3. Damage due to accidents.

Repair and Rehabilitation includes several systematic approaches that are lined up with various strategies to promote a desired level in attaining maximum life of the structure. Generally, life of a structure depends on geography of location, Building material, Technology and Workmanship. Geography of location includes various aspects such as type of strata, water table, earthquake or wind or cyclone or flood or snow, pollutant, landslide and tree location with respect to building. Building materials includes cement, lime, fine sand, coarse sand, quality of water, bamboo or wood, brick. Technology includes various aspects such as architectural design, construction methods, and quality practices. Finally one of the major factor workmanship includes various aspects such as structural work, finishing work, waterproofing work, maintenance of building. The basic process flow employed in Repair and Rehabilitation includes identification of the building that should be rehabilitated, history of the building, preliminary survey which includes preliminary tests that are performed, identification of problems, and suitable solution for the problem which should be feasible to the building topography conditions.



Flowchart-1: Process of Repair and Rehabilitation

The need for Repair and Rehabilitation of structures includes various criteria depending upon the type of structures. These include spalling of structural members, settlement, spalling of non-structural members, leakages in the structure, redesigning of existing structure for nature forces and changed functional requirements. Repair and Rehabilitation plays a major role in construction industry, as it provides a maximum benefits to the surrounding. It acts as a perfect support for the structure that needs immediate maintenance and preservation. Various structures that are being served by repair and rehabilitation are Bridges, Dams, Buildings, where there is an impact of heavy public gathering

and Heritage Buildings. Among construction sector, Repair and Rehabilitation grabs more attention towards heritage buildings. This is because heritage building serves the integrity of culture in and around the world. So it is an important topic to be concentrated for review. In this review a tradeoff between the cost, lifetime and adaptability of the technique is archived, thus providing clear and detailed information regarding the repair methods for the particular problem incurred in the historical buildings.

2. REPAIR AND REHABILITATION OF HERITAGE BUILDINGS- CASE STUDIES

Reported case studies of Repair and Rehabilitation in heritage buildings are prescribed below. The reason for the problem is cited and the solutions existing to resolve the problem are also provided.

2.1 Problems and Causes for the problems identified by the Authors

Sayali Sandbhor, et al proposed their Repair and Rehabilitation work on a building, which was constructed during British period in the year 1871. The author identified various problems such as structural cracks in masonry walls, crack in lime concrete slab, collapse of column portion and roof leakages. These are caused due to poor load distribution, poor waterproofing, seepage of water and water logging [1].

Secondly, C.Natarajan, et al reports the Rehabilitation of St. Lourdes Church, Tiruchirapalli which was built in the year 1890. The author faced various problems such as mold stains and water damage, cracks in the outer brick surface and decay of bricks in the inner surface and erosion on the roof surface. These are also caused due to poor waterproofing, seepage of water and water logging [2].

Fig-1: Roof leakages [1]

Followed by Natarajan, Suresh Chandra Pattanaik, et al did their Repair and Rehabilitation for an institutional building located at Mangalore which was a 75 year old building. They identified several problems such as spalled plaster, fungus growth in walls, cracks in the ceiling and masonry walls, corrosion and spalling of concrete in columns. These are mainly caused by severe water leakages and environmental distress [3].

Fig-2: Arrows indicating Mold stains [2]

Gaby Ruiz Petrozzi, et al in 1917 The authors proposed their Rehabilitation work on a 100 year old adobe church named Santisma Cruz Del Norte, located at the center of metropolitan Piura, built in the year 1917.The authors encountered several issues such as cracks at the corners of the walls and across the back wall, cracks between an RC choir loft and the adobe walls, eroded blocks and cracks at roof level. These were mainly caused due to moisture seepage [4].

Moreover, Nur Liyana Othman et al, proposed their case study in a hospital building named Sultanah Bahiyah located at Alor setar. They inspected several issues such as leakages at ceilings and watermarks, black staining in walls and dampness, corrosion at roof gutter. These are caused due to entry of rainwater through louvers due to shortness oh awning, water seepage from toilet area and environmental factors [5].

Fig-3: Vertical cracks and gaps [1]

Followed by Nur Liyana Othman, Sholihin asad, et al examined a case study on an old hospital building named Sugiri in Indonesia. They encountered several issues such as crack damage on masonry walls caused due to water seepage [6].

James S Cohen, intended his Rehabilitation work on a historic building located in Circa, built in the year 1862. He identified several drawbacks in the building such as two facades in the front side were collapsed, vegetative growth at rear side of the building [7].

Fig-4: Cracks in ceilings and walls [3]

Moreover, Abdul Rehman intended his case study on three historic buildings namely the Sholamur garden, Shish mahal and Jahangir tomb which were built in the year 1640, located at Lahore. He underwent various defects in the building such as, severe damage of perimeter wall, deterioration of beams caused due to termite attack and seepage of water from the roof. Stones in the tomb got deteriorated due to fungus, moisture content and air pollution. Bricks on edge pavements were damaged. Growth of vegetation was also found on the rear side of the building [8].

Fig-5: Cracks at roof surface [4]

Followed by Abdul Rehman, P.G.Asteris, et al carried their renovation work on a holy temple named Zoodohos Pigi located at Athens. This building suffered a severe earthquake in the year 1999 and has incurred several defects such as extensive cracks at the cross vaults, cracks at the main facade of the temple. Due to lack of maintenance in the roof, wearing out of vaulted structure took place.[9].

Furthermore, Ajay Chourasia, et al proposed their Repair work in a building which was severely damaged during Bhuj earthquake named Circuit house (Lal Bunglow) at Jamnagar. They inspected several defects in the building such as, deterioration of jack arch floor, extensive cracks at the ceilings, walls and collapse of column portion due to the effect of earthquake. [10].

Likewise, J Gustavo Tumialan, et al intended their case study on a historic building and a church named Palazzo die Celestini and St.Giorgio church. They encountered several issues in the building such as, collapse of column and wide cracks that initiated crushing failure. In the church, the arches and vaults were damaged due to settlement of column [11].

Followed by J.Gustavo Tumialan, Jack W Gerwick, et al carried their renovation work on a historic timber structure where they identified several problems, timber bracings were exposed to marine borers and were rotten, damages at the end of braces and at the connections, finally there was a damage at the stringers and the caps. [12].

2.2 Solutions for the above said problems by the Authors

Sayali Sandbhor, et al suggested several suitable solutions for the above said problems. Epoxy grouting is used for strengthening of weakened and cracked masonry walls. Jacketing of wall surfaces was made by applying mesh nonferrous steel reinforcements and by filling the gaps with lime mortar. Cracks in lime concrete slab were fixed by welding of steel members. Collapse of column portion was restored by removing the collapsed portion and reconstructing the portion was carried out using same type of stone and mortar. Roof leakages were restored by providing proper slopes and by replacing the corroded members using Lead flashing. [1]

Secondly, C.Natarajan et al advised several solutions for the above said problems such as follows. Soap water under pressure was applied to clean out the surface of mold stains. Cracks in the outer brick surface and decay of bricks on the inner side were repaired by replacing cracked and decayed bricks. Lime mortar grouted along the surface was used to recover erosion of roof surface. [2]

Furthermore, Suresh Chandra Pattanaik, et al advocates various solutions for the said problems. Repair of cracks in walls were cured by chipping of plaster and cutting of V grooves along the length of the crack by Chiseling, the cleaning was made by a high pressure water jet. Wire mesh was fixed along the cracks after which the cracks were repaired with medium structural grade repair mortar. Strengthening of masonry column was implemented by providing Steel Jacketing which is braced with tie rod in a zigzag way. [3]

Followed by Suresh Chandra Pattanaik, Gaby Ruiz Petrozzi, et al propounded several solutions for the said problems. To control wall cracks, strips of galvanized welded-wire fabric were used and they have been tied against the walls. To improve the stability of adobe walls, knee braces were used in the adobe walls and are tied up in the roof truss [4].

Furthermore, Sholihin Asad, et al recommended various suitable solutions for their identified problems as follows. Strengthening of foundation was by enlarging the pile cap and installing two new mini bored pile close to the old one. Cracks were repaired by injection of epoxy grouting. Column jacket were placed for the weaker portion of column along their thickness [6].

Moreover, Abdul Rehman advocates suitable solutions for the problems incurred in his identification of defects. At Shalamar Garden, soil improvement technique was implemented to improve the quality of grass cover and by adding of soil fertilizers. Supply of water to fountains on different traces was originally provided through a network of Terracotta pipes and later it was replaced by Galvanized Iron pipes. At Shish Mahal, new grids of wooden beams were constructed to transfer the load of ceiling; lattice structure was repaired by placing of bamboo strips and to support the structure polystyrene sheets was placed below the ceiling [8].

Ajay Chourasia, et al suggest various suitable solutions for their above said problems such as, cracks were stitched and grouted with Lime mortar. Walls were jacketed with welded mesh wire and mild steel flats along both sides [10].

Followed by Ajay Chourasia et al, J.Gustavo Tumialan, et al recommended certain solutions for their incurred problems. Fiber Reinforced Polymer tendons and laminates were chosen by the authors to eliminate the cracks at the vaults. These laminates and rods were also used to increase the effectiveness of confinement and to prevent the expulsion of masonry pieces under high axial loads [11].

Finally, M.Danieli, et al reported some solutions for their problems incurred in the building as follows. For cracks, plaster were removed and filled up with lime cement mortar, steel wedges were used for wide cracks. Damaged portion of arch and shell surfaces were reinforced and plastered, mesh wires were tied to steel anchors.

3. INFERENCE

The previous section provides the reported problems, reasons for occurrence and its solutions. With this as a platform, an attempt is made to bring an effective solution for a prescribed problem among several reported in literature. This is done on employing a tradeoff between cost, lifetime and adaptability of the solution.

Structural Cracks

For structural cracks there occur commonly known solutions such as Epoxy Injection, Polyurethane Injection and Stitching of cracks. Epoxy injection is well known for its high strength and lifetime. It is most costly and difficult to adapt. In case of Polyurethane injection, the cost for the technique is quite less while compared to Epoxy injection and the strength achieved is also less, but the adaptability of the technique is easy while compared to Epoxy injection. In case of Stitching of cracks, both cost and lifetime are comparatively less but the adaptability of the technique is difficult.

Epoxy Injection

For this technique, the machine and materials required is the Injection pump, Ports and resin or grout. The cost of the injection pump would be around 450 USD or 30,000/- (as on 22/03/2016) [www.groutingpumps.com]. The resin or grout would cost at a range of 35 USD per 25Kg or 2,350/- (as on 22/03/2016) [www.sealboss.com]. For implementation of this technique the cost would be around 600 USD i.e. Rs 50,000 including labor charges. Therefore the total cost of this solution would be around 30,000+2,400(per 25Kg) +50,000= 82,400/- approximately. Looking at the lifetime or validity of the solution, epoxy injection would long stand for around 7 years to 10 years [www.epoxygrouting.com].

Polyurethane Injection

For this technique, the machine and materials required are Injection pump, Injection ports and Polyurethane organic resins. The cost of injection pump would be around 450 USD or 30,000/- (as on 22/03/2016) [www.groutingpumps.com]. The cost of polyurethane organic resin will be around $20 USD per 25Kg resin or Rs1,328/- (as on 22/03/2016) [www.sealboss.com]. For implementing this technique it would cost around 30,000/- including labor charges. Therefore the total cost of this solution will be around 30,000+1,330(per 25Kg) +30,000 = 61,330/- approximately. Lifetime or validity of this solution will be around 5 years to 6 years [www.waterworld.com].

Stitching cracks

In this technique the machines and materials required are stitching bars, nozzle, grout or resin, mixer paddle and finger trowel. The total cost of the stitching kit will be around 118 British Pounds or Rs11,200 (as on 22/03/2016) [www.twistfix.co.uk]. The cost of implementation will be around Rs50,000 including all charges. Therefore the total cost of this solution will be around 50,000+11,200 = Rs61,200 approximately. The life of this solution will be about 3 to 4 years [www.helifixcrack.com].

From the above explanation it is concluded that Epoxy Injection is the best suitable solution for structural crack repair. Though it is expensive and difficult to adapt, lifetime yield of the solution is more while compared to other methods said above. Yielded lifetime of the solution is the major criteria considered for an effective solution especially for heritage buildings.

Roof Leakages

Roof leakages are a predominant problem occurring in a heritage building. The most frequent solutions employed for the same are provided as follows:

- Replacement of damaged roof with new clay roof tile and rearrangement of sealant.
- Replacement of damaged roof portion by asbestos roof and refill of sealant.
- Lead flashing.

Replacement of damaged roof with new clay roof tile and rearrangement of sealant

For this method the needed materials are new clay roof tile, lime mortar and sealant. The cost of sealant would be around 14 British Pounds or 1320/- per Kg (as on 05/04/2016) [www.bostik.com]. Lime mortar will cost about 10 British Pounds or 940/- per 20Kg (as on 05/04/2016) [www.eden-lime-mortar.co.uk]. The cost of clay roof tile is about 40USD or 2660/- per square foot (as on 05/04/2016) [www.buildings.com].The cost of implementation will be around 50,000/-. The total cost of this technique will be around 1320(per Kg) +940(per 20Kg) +2660(per square foot) +50000= 54920/- approximately. The lifetime of a clay roof tile will last long for about 75 years [www.buildings.com].

Replacement of damaged roof with asbestos roof and refill of sealant

In this technique the materials required are asbestos roof, lime mortar and asbestos sealant. The cost of asbestos roof will be around 25USD or 1660/- per square foot (as on 05/04/2016) [www.asbestos.com]. The cost of lime mortar is about 10 British Pounds or 940/- per 20Kg (as on 05/04/2016) [www.eden-lime-mortar.co.uk]. The asbestos sealant will cost at a range of 10 British Pounds or 940/- per Kg (as on 05/04/2016) [www.bostik.com]. The implementation cost of this technique will be around 50,000/-. The total cost of this technique will be around 1660(per square foot) +940(per 20Kg) +940(per Kg) +50,000= 53,540/- approximately. The lifetime of asbestos roof will last long up to 25 years [www.asbestos.com].

Lead Flashing

The materials that are required for this technique are lead flashing sheet, primer flashing strip and primer solution. The cost of lead flashing sheet will be about 30 British Pounds or 2820/- per square foot (as on 06/04/2016) [www.wickes.co.uk]. The cost of primer flashing strip will be about 5 British Pounds or 470/- per square foot (as on 06/04/2016) [www.wickes.co.uk]. The cost of primer solution will range about 2 British Pounds or 190/- per Kg (as on 06/04/2016) [www.bunnings.com.au]. The implementation cost of this technique will come around 50,000/-. The total cost of this solution will be about 2820(per square foot) + 470(per square foot) +190(per Kg) + 50,000= 53,480/- approximately. The lifetime of this technique will be last long over 100 years [www.leadflashing.com].

From the above explanation it is concluded that Lead flashing is the best suited and effective solution for leakages of roof. As said before yielded lifetime of the solution is most considered in case of heritage buildings and so this method is most suited.

Peeling of walls and ceilings

Peeling of walls and ceilings is also a major defect incurred along heritage buildings. *The most suited and effective solution for peeling of walls or plaster is Mughal plastering which is nothing but plastering with Lime mortar.* The cost of lime mortar will be at a range of 10 British Pounds or 940/- per 20Kg (as on 06/04/2016) [www.eden-lime-mortar.co.uk]. The cost for implementation will be around 30,000/-. Therefore the total cost of the technique will be around 940(per 20Kg) +30000= 30940/- approximately. The lifetime of Mughal plastering will last long about 10 years. [www.buildingconservation.com]. Mughal plastering is also considered as an effective solution because of its nice finishing and good aesthetic condition.

Mold Stains

Mold stains are also incurred as a problem among heritage buildings. *The effective solution for this particular problem is Appling soap water under high pressure.* The materials required for this problem are pressure nozzle, pressure controller and tube. The cost of the kit will be around 40USD or 2660/- (as on 06/04/2016) [www.becomethesolution.com]. The cost for implementing this solution will be 20,000/-. The total cost for the technique will be 2660+20000= 22,660/- approximately. The life value of this solution will be around 5 years to 6 years [www.pressurewashersdirect.com].

Vegetation Growth

Another major problem incurred along heritage buildings is this biological vegetation growth. The materials required for the removal of growth are Glyphosate, Ammonia solution and lime mortar. The cost of Glyphosate will be around 70USD or 4660/- per 9.5 liters (as on 06/04/2016) [www.amazon.com]. Lime mortar will cost about 10 British Pounds or 940/- per 20Kg (as on 06/04/2016) [www.eden-lime-mortar.co.uk]. The cost of Ammonia solution will be around 600/- per 2500ml [www.srlchem.com]. Implementation cost for this solution will be about 20,000/-. Therefore the total cost will be around 4660(per 9.5 liters) +940(per 20Kg) +600(per 2500ml) +20,000= 26,200/- approximately. The lifetime will be a default because of its complete removal of vegetative growth and its root and there will be no chance of plant growth in that particular area or portion of the building.

Table -1: Tradeoffs of Suitable methods

Problems	Solution	Tradeoff		
		Cost	Lifetime	Adaptability
Cracks	Polyurethane foam	High	Low	Easy
	Epoxy grouting	**High**	**High**	**Difficult**
	Stitching cracks	Low	Low	Difficult
Roof leakages	Replacement of tile, with new clay roof tile and rearrange of sealant.	Medium	Medium	Light Difficult
	Asbestos roof and refill the sealant	Low	Low	Easy
	Lead flashing	**High**	**High**	**Difficult**
Peeling of walls and ceilings	**Mughal plastering**	**Medium**	**High**	**Moderate**
Mold stains	**Application of soap water under high pressure**	**Medium**	**Maximum**	**Light Difficult**

4. CONCLUSIONS

This paper provides a comprehensive study of repair and rehabilitation of heritage buildings. The existed problems and its reported solutions are finely reviewed. An effective solution for the reported problem is formulated based on tradeoff between cost, lifetime and adaptability of the solution. Hence this paper delivers its usefulness to those who as an objective of doing Repair and Rehabilitation in a Heritage Building.

ACKNOWLEDGEMENT

I would like to thank my beloved Sister for helping and guiding me to write this review paper.

REFERENCES

[1]. S. S. (2013). A Systematic Approach Towards Restoration Of Heritage Buildings- A Case Study. *International Journal of Research in Engineering and Technology IJRET, 02*(03), 229-238.

[2]. Natarajan, C., Chen, S., & Syed, M. (2010). Rehabilitation and Preservation of the St. Lourdes Church, Tiruchirappalli. *J. Perform. Constr. Facil. Journal of Performance of Constructed Facilities, 24*(3), 281-288.

[3]. Suresh Chandra Pattanaik., E Gopal Krishnan., and Mohan Kumar., (2011). "Repair and Rehabiltation of Nehru Memorial College of KVG Group of Institutions at Manglore-A Case Study". *International Conference CEMCOM organized by Indian Concrete Institute at Pune.*

[4]. Petrozzi, G. R., Carbajal, F., & Schexnayder, C. J. (2015). Restoration of a Historic Adobe Church. *Pract. Period. Struct. Des. Constr. Practice Periodical on Structural Design and Construction, 20*(1), 04014026.

[5]. Othman, N. L., Jaafar, M., Harun, W. M., & Ibrahim, F. (2015). A Case Study on Moisture Problems and Building Defects. *Procedia - Social and Behavioral Sciences, 170*, 27-36.

[6]. As'Ad, S., M., & Sukiman, M. (2013). Investigation on Wall Crack Damage and Its Proposed Repair Method. *Procedia Engineering, 54*, 165-175.

[7]. Cohen, J. S. (2011). Problems in the Repair of Historic Brick Masonry Buildings.*Structures Congress 2011*.

[8]. Abdul Rehman., (2011). "Conservation of Historic Monuments in Lahore-Lessons from Successes and Failures". *Pakistan Journal of Engineering and Applied Science.,* Volume 8.

[9]. Asteris PG., AD Tzamtzis., PP Vouthouni., and DS Sophianopoulos., (2005). "Earthquake Resistant Design and Rehabilataion of Masonry Historical

Structures". *Practice Periodical on Structural Design and Construction.,* 10.1061/(ASCE)1084-0680(2005)10:1(49).

[10]. Ajay Chourasia., SK Singh., and Jalaj Parashar., (2012). "Siesmic Rehabilitation of Heritage Structures-Problems and Prospects". *Indian Society of Earthquake Technology held at Indian Institute of Technology, Roorkee.*

[11]. Tumialan, J. G., Micelli, F., & Nanni, A. (2001). Strengthening of Masonry Structures with FRP Composites. *Structures 2001*.

[12]. Gerwick, J. W., Trenkwalder, T. W., & Kearney, J. W. (2010). Practical Repair of Timber Structures. *Ports 2010*.

[13]. Danieli M., and J Bloch., (2012). "Principle, Practice and Experience of Rehabilitation of the Historical Buildings in Seismic Regions".

[14]. Tayeh, B. A., Bakar, B. H., Johari, M. A., & Voo, Y. L. (2013). Utilization of Ultra-high Performance Fibre Concrete (UHPFC) for Rehabilitation – A Review. *Procedia Engineering, 54*, 525-538.

[15]. Bhavar Dadasaheb., Dhake Pravinchandra D., and Ogale Ramesh A., (2013). "Retrofitting of Existing RCC Buildings by Method of Jacketing

[16]. Brar TS., MA Kamal., and RK Jain., (2012). "Seismic Retrofitting of Heritage Buildings-Conservation Interventions". *Indian Society of Earthquake Technology Conference held at Indian Institute of Technology, Roorkee.*

[17]. Harun, S. (2011). Heritage Building Conservation in Malaysia: Experience and Challenges. *Procedia Engineering, 20*, 41-53.

[18]. Mulani, M. H., & Kumthekar, P. M. (2015). Special Materials for Rehabilitation of Monuments. *IJERT International Journal of Engineering Research and, V4*(04).

[19]. Sofronie, R. A., & Bolander, J. E. (2002). New Repair and Rehabilitation Technologies for Masonry Buildings. *Rehabilitating and Repairing the Buildings and Bridges of Americas*.

[20]. Halim, A. A., & Halim, A. Z. (2010). An Analysis of Dampness Study on Heritage Building: A Case Study Ipoh Old Post Office Building and Suluh Budiman Building, UPSI, Perak, Malaysia. *JSD Journal of Sustainable Development, 3*(4).

[21]. Roslan Talib., David Boyd., Susan Hayhow., A Ghafar Ahmad., M Zailan Sulieman. (2015). Best Practice on Prevention and Rectification of Roof Leaking: Selected Malaysia Heritage Building cases. *International Journal of Emerging Technology and Advanced Engineering, Volume 5.*

[22]. Trenkwalder, T. (2009). Seismic Rehabilitation of Heritage Timber Structures. *Tclee 2009*. doi:10.1061/41050(357)92

[23]. Talib, R., Boyd, D., Hayhow, S., Ahmad, A. G., & Sulieman, M. (2015). Investigating Effective Waterproofing Materials in Preventing Roof Leaking; Initial Comparative Study: Malaysia, U.K. Procedia Manufacturing, 2, 419-427. doi:10.1016/j.promfg.2015.07.074

[24]. Pompejano, F., & Merxhani, K. (2014). Preliminary studies on traditional timber roof structures in Gjirokastra, Albania. Vernacular Architecture: Towards a Sustainable Future, 631-636. doi:10.1201/b17393-110

[25]. Lourenço, P. B., Luso, E., & Almeida, M. G. (2006). Defects and moisture problems in buildings from historical city centres: A case study in Portugal. Building and Environment, 41(2), 223-234. doi:10.1016/j.buildenv.2005.01.001.

[26]. Mahdi, T., & Mahdi, A. (2013). Reconstruction and Retrofitting of Buildings after Recent Earthquakes in Iran. Procedia Engineering, 54, 127-139. doi:10.1016/j.proeng.2013.03.012

[27]. Sodangi, M., Khamdi, M. F., Idrus, A., Hammad, D. B., & Ahmedumar, A. (2014). Best Practice Criteria for Sustainable Maintenance Management of Heritage Buildings in Malaysia. *Procedia Engineering, 77*, 11-19. doi:10.1016/j.proeng.2014.07.017

[28]. Sabri, A. M., & Suleiman, M. (2014). Study of the Use of Lime Plaster on Heritage Buildings' in Malaysia: A Case Study in George Town, Penang. MATEC Web of Conferences, 17, 01005. doi:10.1051/matecconf/20141701005

[29]. Lombillo, I., Biezma, M. V., & Villegas, L. (2015). Construction Rehabilitation in Civil Engineering at the Bachelor Degree Level: Guideline Course. J. Perform. Constr. Facil. Journal of Performance of Constructed Facilities, 29(2), 04014052. doi:10.1061/(asce)cf.1943-5509.0000540

[30]. Arthur L Sanders., AIA and Kevin Magness, AIA (2007) *Brick Maintenance and Repair for Historic and Landmark Structures. Journal of Architectural Technology.*