Senarathne, H.N.Y. and Asmone, A.S., 2023. A taxonomy of waterproofing systems for high-rise building projects in the tropics. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 47-58. DOI: https://doi.org/10.31705/WCS.2023.5. Available from: https://ciobwcs.com/papers/

A TAXONOMY OF WATERPROOFING SYSTEMS FOR HIGH-RISE BUILDING PROJECTS IN THE TROPICS

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ABSTRACT

The building construction is the most significant sector that has acquired significant attention in recent years among the various construction industries and the necessity of erection of high-rise buildings was emphasised because of the restricted space in urban areas. Since the unique and complex characteristics are involved in a building project, the structure must be strong enough in terms of its durability, stability as well as the appearance. Accordingly, water is the most persistent opponent of a high-rise building, and gradually, building components might erode, compromising their structure and requiring costly repairs. Thus, the purpose of this study is to examine the factors that influence the choice of the best waterproofing system in high-rise building projects in the tropics. Semi structured interviews were used to determine how the factors affected the choice of waterproofing. All respondents were project managers or engineers with extensive backgrounds in the building sector and expertise in waterproofing. Collected data were analysed using manual content analysis. The taxonomy was created using the opinions of experts and contractors on the choice of waterproofing. The most important category in the Taxonomy was related to detailing technology, while the least important category was related to legal requirements and compliance.

Keywords: *Construction Industry; Highrise; Taxonomy; Waterproofing.*

1. INTRODUCTION

Water is the most persistent opponent of a high-rise building, and gradually, building components might erode, compromising their structure and requiring costly repairs (Jonathan, 2013). Leakage, rising dampness, and water seepage may occur not just in old buildings but also in modern buildings (Mydin et al., 2017). Repairing the failure of the waterproofing membrane is the most expensive investment when it comes to leaking (Basheer et al., 2001). As argued by Sriravindrarajah and Tran (2018), waterproofing is necessary for every surface area that comes into touch with water, has the potential to let water in, or could result in water getting inside a building. Further to the author, waterproofing may be considered high-risk or important when it is over a dwelling space. Defects and deficiencies due to the poor waterproofing in the building might have a negative view and affect all stakeholders, whether explicitly or implicitly (Mydin et al., 2017). Customers are dissatisfied due to the aspects of less stability and durability of the

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structure (Karunasena & Ranatunga, 2009). Since proper waterproofing helps to maintain the integrity of the building while lowering maintenance costs of the building, it is a key aspect in building construction (Sriravindrarajah & Tran, 2018). Prior to selecting a waterproofing system, an architect or waterproofing designer must consider numerous factors such as material, water table, soil characteristics, substrate stability, construction sequence, risk vs. cost, ease of application, codes and standards, contractor competencies etc. (Grachev, 2021). Since there are number of factors affecting to the decision on waterproofing selection, evaluation of those might be beneficial when selecting suitable waterproofing system to a building (Kimick et al., 2021). Apart from that, despite the fact that many studies have been conducted on waterproofing as a defect (Chew, 2005; Sokova & Smirnova, 2019), researchers have not focused on how to select proper waterproofing considering their significant factors. That facet might be viewed as a major contribution to current knowledge gap. As a result, overcoming the knowledge gap can be termed a prevalent necessity and therefore, the study investigates, how to select most suitable waterproofing system in high-rise buildings in the tropics by considering significant factors.

2. LITERATURE REVIEW

2.1 WATERPROOFING IN HIGH RISE BUILDINGS IN THE TROPICS

The region of land and ocean between the Tropic of Cancer (latitude 2 3.5/N) and the Tropic of Capricorn (latitude 2 3.5/S) is known as the tropical zone (Wahab et al., 2013). Further to the author, although the tropics itself have a variety of climates, 90% of the tropical zones reflect hot, humid climate regions, whether year-round or seasonal. Many construction issues have unavoidably arisen as a result of the rapid expansion of new development in tropical areas (Briffett, 1991). This indicates that structures in tropical regions have a tendency to age quickly, especially when it comes to exterior construction materials that are exposed to elements like rain, wind, sunlight, ultraviolet light, and air pollution (Ahzahar et al., 2011). All high-rise buildings are vulnerable to extreme humidity and a lot of rain (Bahadur, 2017). Interior, external, and sub-grade works are the three main areas to be considered when waterproofing high rise buildings and thorough waterproofing system is made up of a number of interrelated elements, including substrate preparation, membrane detail, drainage design, design, installation, quality assurance, and maintenance (Sriravindrarajah & Tran, 2018). More than 50% of the structures had issues with interior water leaks, which contributed to their high life cycle costs and high maintenance, repair, and replacement requirements over their useful lives (Chew & De Silva, 2002). In order to preserve a building's aesthetic qualities, avoid structural damage, and ensure the occupants' safety, waterproofing has become a crucial part of the construction (Fonseka et al., 2014). Leaks at structural components including the roof, wall, and ceiling are the primary source of moisture issues in buildings (Othman et al., 2015). For instance, among the 14 key defects at walls and floors highlighted by Chew (2005), are water leaks through cracks, pipe penetration, and joints. As per Grachev (2021), wetting of enclosed structures can happen from moisture intrusion into a building's walls, moisture condensation in the wall material as a result of temperature changes, moisture in the form of precipitation above ground, and moisture in the underground due to groundwater which results reduction in the thermal insulating capabilities of structures, their early demise, and a breach of the indoor microenvironment.

2.2 ISSUES AND IMPACTS OF POOR WATERPROOFING

By reviewing the scholars (Panchal et al., 2015) which have defined the waterproofing in different ways, simply the waterproofing is a formation of barrier on the surface that comes into contact with water, has the potential to ingress water, or poses a risk of allowing water to enter the structure. Staining, cracks, peeling paint, discoloration, corrosion, stalactite and stalagmite, mould growth. Condensation, water patches and dampness, concrete spalling, temperature difference in indoor and outdoor, stagnant water, dirt collection on the surface, nasty odour, water penetration, wood decay and insect infestation are the identified common causes of poor waterproofing through peer reviews (Garcia, 2018; Heseltine & Rosen, 2009; Kumar, 2020; Othman et al., 2015; Sriravindrarajah & Tran, 2018; Stock & Meadow, 2012).

According to Nguyen et al. (2020), due to the decay of the concrete, seepage in building structures is a problematic issue that has many adverse impacts on the calibre, effectiveness, and long-term durability of buildings. Leakage has a number of impacts that can harm other building finishes and result in health issues because of the formation of mould, fungus, dust mites, as well as other biological air contaminants (Panchal et al., 2015). Damage to the building itself is costly, with building owners and tenants bearing a significant share of the cost, including absenteeism due to illnesses such as asthma, reduced productivity as a result of moisture-related health and comfort issues, increased insurance risk, repair and replacement costs for corroded structural fasteners, wiring, and moisture-sensitive materials, costs of repairing and replacing damaged furniture, products, and supplies, uselessness of building spaces following damage and during repairs insurance and litigation costs associated with moisture damage claims have risen (Heseltine & Rosen, 2009).

2.3 IMPORTANCE OF WATERPROOFING

Building structural defects should be taken seriously because they are a source of tremendous concern since both the home buyers and the inhabitants will have various concerns when a structure does not perform up to expectations or at all (Mydin et al., 2017). Building envelops will remain untouched and avoid needless repairs by regulating groundwater, rainwater, and surface water because water may seriously damage concrete, masonry, and natural stone buildings (Kubal, 2008).

If the requirement to keep the building as dry as feasible is not met, it is likely that the building will become inhabitable and unsafe structurally (Panchal et al., 2015). As per Sokova and Smirnova (2019), waterproofing is essential for guaranteeing standards-compliant durability and secure conditions. Sriravindrarajah and Tran (2018) has demonstrated that the appropriate waterproofing system is robust enough to drain water away from the source. The best solution will increase the maintainability and longevity of the operation of buildings and structures, reduce the complexity of the work on the implementation of repair work with hydraulic protection of structures, and determine long-term and reliable waterproofing by selecting the most optimal materials and technologies (Sokova & Smirnova, 2019). If neglected, inadequate waterproofing not only compromises building safety but also poses a risk to hygiene (Wong & Hui, 2005).

2.4 CHALLENGES OF WATERPROOFING

The inability to determine the root and source of the seepage, accessibility issues, underutilisation of the expertise and experience of the building professionals in seepage preliminary investigation, inadequacy of current testing methods and equipment, and some defendant owners and occupiers' reluctance to collaborate with the relevant parties and public officials are the main issues with handling seepage complaints (Wong & Hui, 2005). Water proofing and drainage are two areas where most contractors lack knowledge, and they are frequently completed in an ineffective manner, resulting in water seepage through the roof ceiling or block wall (Assaf et al., 1995). Most of the manufacturers do not have trained, inspected, licensed, or approved contractors to install their waterproofing materials, and most manufacturers also do not provide performance guarantees for waterproofing membranes (Pratt, 1990).

Whereas most builders concentrate on aesthetic and design components to waterproof the structure, it has been observed that key areas such gaps between walls, wall coatings, and tiles of the building terrace that would also adversely affect the waterproofing are given comparatively less attention (Bahadur, 2017). Once the concrete is poured, the blind side waterproofing cannot be assessed and even if the membranes are put after the concrete has been cast, it is too late to repair improper installation once the waterproofing has been buried (Kadlubowski & Yates, 2010). Further to the author, if the system fails, rehabilitation may necessitate extensive excavation and rebuilding of surface, landscaping, and wall systems. As argued by Panchal et al. (2015), even the most difficult waterproofing applications can be solved with some careful investigation and innovative water management solutions.

2.5 FACTORS TO CONSIDER WHEN SELECTING WATERPROOFING: WHAT DOES LITERATURE TELL US?

The ideal solution will decrease the complexity of the work required to implement repair work with hydraulic protection of structures, increase the maintainability and durability of the operation of buildings and structures (Sokova & Smirnova, 2019). Table 1 provides a summary of the research's findings with reference to the deciding criteria in the selection of waterproofing. Further the 31 sub factors were categorised into 7 main factors.

Table 1: Factors to be considered when selecting waterproofing.

No	Sub Factors	Main Factors	Source
01	Application site	Material	[1][2][3][4][5][6][7][8]
02	Purpose of application		
03	Recommendation of suppliers		
04	Standards		
05	Useful life (durability)		
06	Easy application		
07	Resistant to UV		
08	Comfort of the interior		
09	Porosity and the strength of materials		
10	Sustainability of materials		
11	Design rules		[2][3][4][5][6][7][8][10][11]

No	Sub Factors	Main Factors	Source
12	Mechanical effect	Detailing and technology	
13	Special skills and equipment		
14	Testing requirements		
15	Composition of the structural elements of the building	Building profile	[2][6][7][8][12]
16	Operating condition of the building		
17	Water table and soil characteristics of the building location		
18	Occupancy		
19	Cost of materials	Cost	[2][5][6][7]
20	Required investment		
21	Labour cost		
22	Changes in the temperature and humidity	Climate and environment	[2][3][13]
23	Chemical composition of groundwater		
24	Codes and Standards	Legal requirements and compliance	[2][5][9]
25	Reputation	Suitability of contractor	[5][12][13]
26	Capability to undertake the works		
27	Water proofer's history on similar projects		
28	Financial position		
29	Available human resources		
30	Ability to meet all the environmental, safety, quality, statutory and government requirements, and regulations		
31	Ability and confidence to warrant the product		

Sources: [1] Kimick et al., (2021); [2] Grachev, (2021); [3] Kubal, (2008); [4] Othman et al., (2015); [5] Sriravindrarajah & Tran (2018); [6] Mydin et al., (2017); [7] D'Annunzio, (2014); [8] Kumar, (2020); [9] Windapo & Cattell, (2010); [10] Panchal et al., (2015); [11] Larisch, (2016); [12] Chew & De Silva, (2002); [13] Kadlubowski & Yates, (2010)

The selection of material, detailing and technology, and associated cost are the primary criteria that are frequently mentioned and have a significant impact on the choice of waterproofing, according to the findings of the aforementioned literature review.

2.5.1 Material

By selecting the best materials and methods, waterproofing must now be determined to be long-lasting and dependable (Sokova & Smirnova, 2019). The protective materials must not only waterproof the building but also shield the concrete and/or masonry from assault by corrosive substances that are dissolved in water or found in the soil or other nearby materials (Pratt, 1990). Long-term waterproofing failures were caused, among other things, by a lack of knowledge about the methods and the choice of incorrect materials (Kimick et al., 2021; Song et al., 2017).

2.5.2 Detailing and Technology

The construction industry has seen technological breakthroughs in waterproofing materials over the last two decades, including integral waterproofing systems and more modern membrane materials (Panchal et al., 2015). The risk of water seeping into the structure could be decreased by using technology more effectively during the project's design, construction, and post-completion phases, such as scheduling waterproof membrane installations and selecting qualified and experienced water proofers to supply and install membranes, designing landscaped areas around movement joints, avoiding low-priced tenders, and performing adequate inspection and maintenance to detect flaws (Sriravindrarajah & Tran, 2018).

2.5.3 Cost

Waterproofing structures is a fairly time-consuming and responsible process that accounts for up to 3% of the total labour costs for building a structure (Grachev, 2021). Further to the author, it is estimated to cost between 0.1% and 0.5% of the estimated cost of construction and installation work. Failures in the waterproofing process have an impact on both project participants and building occupants (Sriravindrarajah & Tran, 2018). However, Sriravindrarajah and Tran (2018) further stated that, when awarding waterproofing contracts to subcontractors, financial considerations shouldn't be the single determining factor.

2.5.4 Building Profile

Selection of waterproofing is varied based on the building profile due to its uniqueness (Chew & De Silva, 2002). Unlike any other outside building component, waterproofing materials are distinctive in that they are subjected to substantially tougher environmental conditions (D'Annunzio, 2014; Kumar, 2020). Further to the authors, at the waterproofing surface, the majority of the exposure elements are always present and do not wane as they do at the other outside components.

2.5.5 Climate and Environment

Being constantly exposed to a range of climatic and environmental components, such as wind, sunlight, temperature, rain, and other factors, causes buildings all over the world to interact with their local climate in unique ways (Kubal, 2008). Further to the author, this is why different building designs and construction techniques are used in different places to address various issues. For instance, the average air temperature affects the thickness and quantity of insulation in a building, with colder places needing more insulation to retain heat (Othman et al., 2015). As a result of the amount of rain that falls there each year, buildings needs to address the issue of waterproofing (Kadlubowski & Yates, 2010).

2.5.6 Legal Requirements and Compliance

Since buildings play such a significant role in environmental health, living standards, and economic stability, it is critical to encounter standard guidelines, regulatory controls, and criteria to regulate their design, construction focusing on the structural stability (Windapo & Cattell, 2010). Further to the author, as one of the most significant factors to consider is statutory requirements, and when selecting the best waterproofing system, it is critical to choose manufacturers who are code compliance and industry certified.

2.5.7 Suitability of Contractor

The skill of the waterproofing applicator and the calibre of the membrane should be taken into account as the primary deciding elements (Chew & De Silva, 2002). When contractors don't take care with materials and installation, even the most meticulous and demanding drawings and specifications are of little help and for instance, damage from heavy machinery and irresponsible backfilling are two major causes of waterproofing failure (Kadlubowski & Yates, 2010).

3. RESEARCH METHODOLOGY

The methodology is the approach used to carry out the intended study objectives. Initially, a comprehensive literature review on the waterproofing in high-rise buildings and factors to be considered in selection of proper waterproofing was carried out. Secondly, Secondly, industry experts in waterproofing were approached for semi-structured interviews in order to gather data from many angles. Purposive sampling was used to select experts since it allows the researcher to gather information from others who hold similar opinions (Etikan & Bala, 2017). Additionally, using purposive sampling allows for the effective use of time and other resources while collecting information from the most knowledgeable experts (Palinkas et al., 2015). The sample size was limited to ten participants, since after the sixth interview, the data was appeared to be more stable. Table 2 shows the details of the respondents who were participated to the expert interviews.

Table 2: Details of the respondents

Respondent	Profession	Designation	Experience in the industry
R01	Engineering	Chief engineer	30 years
R02	Engineering	Director	35 years
R03	MEP Engineering	MEP Manager	15 years
R04	Engineering	Project Manager	27 years
R05	Engineering	Project Manager	25 years
R06	Engineering	Site Engineer	11 years
R07	Engineering	Site Engineer	10 years
R08	Safety Engineer	Maintenance Engineer	10 years
R09	Engineering	Project Manager	25 years
R10	Engineering	Project Manager	20 years

Regarding expertise, all respondents possessed sufficient industrial experience in the waterproofing industry, along with at least 10 years of construction industry experience, to contribute to the study with their technical and professional understand. The fact that only ten experts were selected to participate in the semi-structured interviews highlights how important and acceptable qualifying experience is. As a result, the information profile of research participants shows that the data acquired is credible. The primary objective of the expert interviews was to assess how effectively the conclusions of the literature review applied to waterproofing system. Accordingly, most influencing sub-factors (31 Nos) were identified under different categories (7 Nos) with the help of previous literature. 10 experts in construction industry were asked questions focusing on main factors to be considered in selection of waterproofing. Manual content analysis was chosen as the best data analysis technique for the research in order to have a thorough

understanding of the textual and qualitative data gathered through the interviews, to conduct a flexible data analysis, and to have the researcher reasonably interpret the results of the analysis. Finally, Taxonomy was developed analysing gathered data from expert interviews.

4. RESULTS AND DISCUSSION

Information gathered through the expert interviews were analysed using manual content analysis. Based on the expert opinions for main factors, Taxonomy was developed (Refer Figure 1).

As agreed by all respondents, cost and suitability of contractor are the most considerable factors when selecting waterproofing system in terms of client or owner of the project. There is no doubt that the scarcity of funds is always a constraint, in the context of a construction, renovation or replacement. However, if a building owner or general contractor wants to cut costs, the waterproofing system is not the place to do so. As noted, the cost incurred for even minor repairs could easily exceed the initial cost of the system (D'Annunzio, 2014). Further, suitability of contractors should not be the first consideration still they need to be considered because some reasons such as competitiveness in the market.

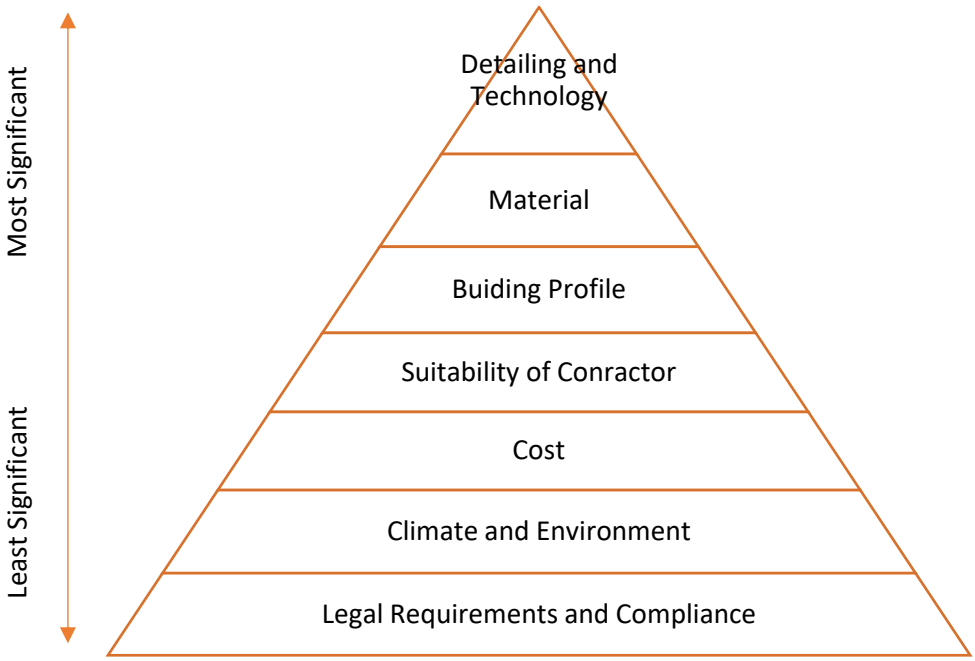

Figure 1: Formulated Taxonomy

Consequently, Taxonomy (Refer Figure 1) represents the view of an expert regarding the criteria that should be considered sequentially while choosing waterproofing. Simply expressed, the Taxonomy illustrates the hierarchy of considerations that must be considered while choosing the appropriate waterproofing. The most important category for affecting the choice of waterproofing, according to Figure 1, was one associated towards detailing and technology, whereas the category with the least influence was one related to legal requirements and compliance. While selecting the optimal waterproofing

solution, the final results provided a clear understanding of the most important decision factors.

As agreed by all respondents, long-term waterproofing problems were caused by, among other things, a lack of knowledge about the detailing and the choice of incorrect materials. R05 stated that, "*The waterproofing will fail for sure if you don't match the thermal insulation qualities with your choice. Even if you use the greatest material or waterproofing, poor technical details will lead to poor waterproofing*".

No one pays attention to enhancing the essential and frequently crucial detailing that is required to transition from one building facade component to the next, despite the fact that individual waterproofing materials and systems continue to advance. Although the structural design of waterproofed building components is outside the scope of the manual, a waterproofing designer is nevertheless required to have a basic grasp of waterproofing design concepts and techniques (Henshell, 2000). Further, applying a product with higher performance saves costs on the application and maintenance of the building. The outcomes of the finding from the expert interviews were also supported by these literary findings. The third important consideration, according to experts, is the building profile since using the right waterproofing system for the location in concern is essential to choosing the finest solution. R07 stated that, "*The appropriate waterproofing system should be utilised in accordance with their region of specification*".

As there are still instances of infiltrations, which may be attributed to a lack of trained specialists in the region or a failure to carry out the proper execution, the eligibility of the contractor needs to be considered before the cost is evaluated. The waterproofing system is not the place to minimise expenses, according to experts, whether a building owner or general contractor wishes to do so. R01 stated that, "*Severe corrective treatment might sometimes cost more than 300 times the price of the membrane. First cost is therefore not a good initial consideration to consider when making decisions*". Since, after installation of the waterproofing layer, it is not severely exposed to the environmental conditions it is not thought to be the most important aspect. Moreover, waterproofing practices are not legally required, and they are regarded as the least important factor.

4.1 USAGE OF TAXONOMY

The suggested taxonomy may be used to provide recommendations to avoid choosing a waterproofing that is useless and misleading. By using this Taxonomy, Mitigate the frequency of replacement and refurbishment of waterproofing can be mitigated since the optimum solution will be selected through this Taxonomy. Further reducing the requirement of maintenance, maintaining the structural stability and appearance of the building through a best waterproofing solution and ensuring the safety and comfort of the occupant by avoiding poor waterproofing defects are some of the key benefits that can be gained by adapting this Taxonomy while making the decision on selection of waterproofing. Moreover, by reducing resource wastages through reducing the waterproofing defect rectification value for money can be ensured. The Taxonomy developed, including research findings was recommended for the reference of industry practitioners who are involved in waterproofing buildings in the tropics, for the identification of the strategies for the enhancement of the quality of the building and structural stability. Further the developed taxonomy can be incorporated during the initial design and construction stages of the buildings and post occupancy buildings which require remedial waterproofing.

5. CONCLUSIONS

Waterproofing is an essential topic to be researched as it has direct influence on the building in the tropics. In this research, 31 sub factors were evaluated under 7 main factors. As the final objective, all the seven factors were ordered according to the significance of them. Hence, taxonomy was developed considering waterproofing selection criteria. Most influencing factor was selected as detailing, and technology related factors and least influencing factor was considered as legal requirement and compliance. As the result shows, a waterproofing system can be characterised as a set of materials, preparation of specifications, and application methods created while taking the client's or owner's needs into account to provide concrete structures with effective, dependable, and long-lasting protection while requiring the least amount of maintenance. Hence, it can be inferred that the ideal solution will lessen the complexity of the implementation of repair work with hydraulic protection of structures, raise the maintainability and lifespan of the operation of buildings and structures. Consequently, this research contributes to the future construction industry as a framework to decision makers who are engaged in waterproofing projects. Further, in order to further enhance the quality and accuracy of the decision of selection, it is recommended to monitor these factors through the reinforcement learning to imitate the way of humans learn.

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