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DOME CONDITIONS IN COASTAL CITY IN TROPICAL CLIMATE

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ABSTRACT

The paper describes the long-term monitoring of the finishes performance of the building with dome structure located in coastal area. The theoretical proposal is based on relevant literature and was applied and adjusted in a survey of 24 buildings. Majority building in the study is composed of mosque buildings and followed by government buildings and business and office building. As the building must also be in good condition to serve their purpose, there was concern about the effect of the outdoor factor on the durability of the building finishes. The main objective of the monitoring was to assess the effect of the environment in coastal area on the building finishes. The study included the correlation between dome condition with age, coastal distance, mean sea level height, material finishes and dome size. This paper explains the monitoring and results approach. The results indicated that the finishes use of various building materials has a different effect on the outer finishing conditions of the dome. Majority dome using concrete finish is in good condition compared to the dome that uses metal sheet finish. This defect can be seen from the connecting part of the metal sheet panel. This is due to the incorrect or inaccurate installation method.

KEYWORDS: Building Envelope, Dome Condition, Coastal City, Tropical Climate, Condition Survey Protocol 1 Matrix.

INTRODUCTION

A dome is a type of a roof structure that looks like a half of a sphere. They can be churches, mosques, synagogues, sports arenas, igloos, government buildings or dwellings. Dome structures are used in buildings of different shapes and functions. Dome was also designed as a sharp, cool and innovative idea that can facilitate sport's industry in desert-covered areas which is the Shaded Dome™ which was designed in a way that it actually constitutes a smart, cool and adaptable facility, which meets the highest standards of comfort, sustainability, flexibility, accessibility, safety and security for both its visitors and users, protecting them from the often harsh or unfavourable climatological conditions.[1]

Rehabilitation of buildings accounts for an increasing proportion of design and construction activities. One of the challenges is the control of heat, air and moisture flow through the building envelope. The buildings usually experience a change in indoor climate, because higher standards of comfort are required higher humidifies and better temperature control. Changes should not adversely affect the long-term durability of the building envelope.[2] The paper describes the long-term monitoring of the finishes performance of the building with dome structure located in coastal city.

Building Envelope

The concept of building envelopes is associated with the design and construction of the exterior of a building. A good building envelope involves using exterior wall materials and designs that are climate appropriate, structurally sound and aesthetically pleasing. These three elements are vital factors in constructing the building envelope. The building envelope is determinant for the comfort level of a building. In this context, facades define the building's appearance, simultaneously working as a barrier to external aggressions and a communication element between inside and outside (through light, visibility and ventilation).[3] Facades play a fundamental role on the building's performance, being a complex system to design, build and maintain.[4,5] Facades are composed of walls, openings and different types of claddings (continuous or discontinuous, directly or indirectly fastened). Identifying the facade's components is useful to determine the maintenance needs, according to the most probable anomalies and causes. To evaluate the facade's durability performance, it is necessary to know the aggressive agents to which the facade is exposed.[5] Humidity is the main cause of anomalies in facades, but loads, stress, deformation, radiation, extreme temperatures, dirt, pollution, salts, bacteria, plants, mould, insects, birds, to name a few factors, combined with poor constructive details, may also significantly affect the facade's performance. They may originate stains, cracks, detachment, cohesion loss and fastening defects. The facade of a building requires periodic maintenance like all the other major systems within the building;

although the roof is widely recognized as needing preventive maintenance, few owners understand that the vertical closure also requires a similar commitment to preventive maintenance.[6]

The roofs are a critical part of the building envelope and are highly susceptible to the constantly changing weather and other environmental changes, thereby, influencing the indoor comfort conditions for the occupants. Roofs account for large amounts of heat gain or loss, especially, in buildings with large roof area such as sports complexes, auditoriums, shopping malls and many others. With energy efficiency becoming a crucial goal, the roof is expected to perform functions beyond merely providing a waterproof surface on the top of the building.

Thus a good roofing design, the use of good materials as well as proper maintenance is of great importance to provide the building occupants a longer lasting shelter and comfort. Proper maintenance management has effect on the reliability, safety, availability and quality of the building.[7] Roofs can be covered with many different materials. These can be organized conveniently into two groups; those that work well on steep roofs and those that work on low-slope roofs. Steep roofs usually utilises fabricated materials and applied in small and overlapping unit as well as sheets such as slate, tiles, fired clay and metal sheets among many others. The reason for this use is that these materials are easy to handle and install. The repair maintenance is easy to handle as well. Low-slope roofs have none of these advantages. Water drains relatively slow from the surface and small errors in the construction of the roof may cause them to trap puddles of standing water. However, a building with a low-slope roof has a much simpler geometry that is often less expensive to construct. These roofs, when appropriately detailed, can also be used a balcony, decks, landscape gardens as well as parks. Materials used are usually reinforced concrete as well as precast slab.

Dome Structure

To name one of the steep roofs which had been used centuries ago is the dome structure and these structures can still be seen used in the twenty-first century. The uniqueness and aesthetically pleasing design of the dome has compelled the continuous usage of this structure by designers since the beginning of time until today itself. The advantages of dome structures are its strength which is highly durable and strong.

While the average building life is measured in decades, the dome structures can be measured in centuries. Having fire, water, and wind resistant, these structures are impervious to hurricanes, tornadoes, fires and other threatening natural disasters. However, depending of the materials used and the quality of the materials, the durability and strength of dome structure can vary. Previous studies had investigated on the conditions of masonry domes. Large and of early masonry domes puts forward a typical condition feature of masonry domes: a rather diffused cracking along meridian lines which puts a serious concern for the safety of the dome is a direct consequence of the crack pattern, thus putting a safety concern on dome structure.[8] However, in today's time, dome structures are built using different types of material namely reinforced concrete, steel, glass, steel fibres, mosaic, iron plate to name a few. The finishes of the structure may also differ such as the use of paint coatings or cladding. The combined usage of these materials plays an important role on the durability of the roofing system. Poor buildability and selection of materials and its quality will put a strain on the maintenance of dome structures.

Thus, the need for an assessment of dome structure is important to identify the condition of the structure and the attributes to the condition of the structure. Now the question arises, what are the factors that affect the condition of dome structures? The lack of assessment conducted on the modern day dome structure presents a limitation to know factors that affects the performance and durability of dome structure. This assessment is important in terms of the maintenance aspect as early detection on the characteristic and traits that affect the durability of the dome structure may be identified. This information may assist on the next course of repair works or maintenance work of the structure by providing information on the root cause of any conditions of the structure. Building structure or element defect become inconvenience to the occupants and building owners.[9]

OBJECTIVE

The purpose of this study is to assess the conditions of dome structures available in coastal city of Kota Kinabalu Sabah were in tropical climate, via site inspection and by using a Windows application that utilises the Condition Survey Protocol (CPS) 1 Matrix as well as handing out survey forms and identifying the factors that affects the condition of the dome structure.

METHODOLOGY

Participants and procedure

A total of 24 building with 82 domes structure are has been accessed using the condition survey protocol 1 matrix (CSP1) method to get the actual condition. The study consists of 24 buildings and can be categorized into three main clusters, namely religious buildings or mosques, government buildings and business and office buildings. Most of the buildings that use the dome are mosque buildings where the dome is seen as a landmark and symbolic building of the mosque While the next category is government buildings that also use the dome as a building that can highlight the uniqueness of the building. Meanwhile, it is also the last category of business and office building.

All the data obtained from site inspection has been analysed through two stages. At the first stage all data is sorted by appropriate category and scale. All of these data were categorized into five or six categories according to the suitability of the data range and the factors affecting the dome condition. The second stage analysis involves statistical tests of using the IBM SPSS Statistic 24 software. This data has been processed in terms of conditions frequency to either, fair or dilapidated condition. This data has also been comparable between the dome conditions and the factors that are likely to cause the current condition of a dome.

Instruments

The purpose of conducting a building inspection is to assess the building's condition. Traditionally, building surveyors have primarily relied on descriptive longhand surveys. This means that surveyors recorded every detail by hand when performing on-site building inspections. Through this type of approach, the building survey report is usually longer, more detailed and more technical which propels the need for a quick and practical approach in performing building inspections under reasonable property conditions.

The goals behind the CSP1 matrix,[10] are to;

a. Enable the surveyors to collect data within the shortest possible time by avoiding descriptive, longhand write-ups during fieldwork;
b. Record the existing defects of the building, the main source of data, by assessing the condition and assigning priority or repair to each defect recorded;
c. Obtain an overall rating of the building's condition. The proposed remedial work is not the main concern of this matrix. Moreover, the repair work usually cannot be carried out

immediately after the survey's completion because of budget constraints. Therefore, the validity of any proposed remedial work would need to be reconfirmed later; and

d. Use the numerical rating acquired from the survey work to perform statistical analysis.

The data required for the CSP1 matrix are the condition and the priority assessments, as shown in Tables 1 and 2. Each numerical score (1 to 5) is accompanied by a scale value and description. This will help surveyors to rate the building's defects and to determine the exact condition implied by the scale values. The scale values and their descriptions depend on the maintenance standard of the building being evaluated.

Table 1: Condition Assessment Protocol 1

Condition	Scale Value	Description
1	Good	Minor Servicing
2	Fair	Minor Repair
3	Poor	Major Repair/Replacement
4	Very Poor	Malfunction
5	Dilapidated	Damage/Replacement of Missing Part

Table 2: Priority Assessment

Condition	Scale Value	Description
1	Normal	Functional; cosmetic defect only
2	Routine	Minor defect, but could become serious if left unattended
3	Urgent	Serious defect, doesn't function at an acceptable standard
4	Emergency	Element/structure doesn't function at all; or Presents risks that could lead to fatality and/or injury

Each recorded defect is assigned a condition and priority rating. Each rating is then multiplied to determine the total score for each defect. The total score is then matched with the matrix, as shown in Figure 1. The scores range from 1 to 20.

Scale		Priority Assessment			
		E 4	U 3	R 2	N 1
Condition Assessment	5	20	15	10	5
	4	16	12	8	4
	3	12	9	6	3
	2	8	6	4	2
	1	4	3	2	1

Fig 1: The Matrix.

After scoring every defect, the overall building rating is calculated, which summarises the building's condition. The score of each defect is added up and divided by the total number of defects to get the overall building rating. The building is then rated good, fair or dilapidated, according to the score (out of 20). Table 3 shows the overall building ratings. An executive summary will be produced to present the final findings.

Table 3: Overall Building Ratings.

No	Matrix	Score
1	Good	1 to 4
2	Fair	5 to 12
3	Dilapidated	13 to 20

RESULTS AND ANALYSIS

Independent variables were compared with dependent variables for strength of association and tested using chi-square computed with SPSS for Windows. The null hypotheses were that there would be no significant association between independent and dependent variables.[11] A total of 24 building with 82 dome structures in coastal area of Kota Kinabalu was assessed. From Table 4 can find only one dome are built in 1960s and represent 1.2% of the total dome in the scope of the study. This dome is not a dome designed from its original construction as it is a modification of the function of the original function of the building from a church to the mosque. Majority dome in Kota Kinabalu with 37.8% or 31 number from study population are built in year between 2000 to 2009. While second highest dome are built in 1970s where all 17 dome are newly built for first dome in Kota Kinabalu which is building of Sabah State Mosque.

Table 4: Dome Age (Decades).

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1960s	1	1.2	1.2	1.2
	1970s	17	20.7	20.7	22.0
	1980s	14	17.1	17.1	39.0
	1990s	5	6.1	6.1	45.1
	2000s	31	37.8	37.8	82.9
	2010s	14	17.1	17.1	100.0
	Total	82	100.0	100.0	

There are various types of dome finishes which are the options built in the study area. Popular dome finishes are from aluminium, metal zinc, aluminium composite panel, stainless steel, polycarbonate and concrete. The basic structure supporting the dome load is from concrete structure while the frame supporting the dome finish is from Mild Steel Hollow material. The dome finish of Metal Zink is very popular with a percentage of 41.5% or 34 dome. While concrete finish is the second packaging option with a total of 30 dome representing 36.6% of the total number of studies. These details can be referenced in the following Table 5.

Table 5: Dome Materials.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	S=Concrete / Fr=MS Hollow / Fi=Aluminium	7	8.5	8.5	8.5
	S=Concrete / Fr=MS Hollow / Fi=Metal Zink	34	41.5	41.5	50.0
	S=Concrete / Fr=MS Hollow / Fi=Aluminium Composite Panel	6	7.3	7.3	57.3
	S=Concrete / Fr=MS Hollow / Fi=Stainless Steel	4	4.9	4.9	62.2
	S=Concrete / Fr=MS Hollow / Fi=Polycarbonate	1	1.2	1.2	63.4
	S=Concrete / Fr=Concrete / Fi=Concrete	30	36.6	36.6	100.0
	Total	82	100.0	100.0	

Coastal city is a city or city located on the shore and near the sea. Buildings that surround the coast are exposed to winds from the sea carrying air that contains saline and heat. The influence of the distance from sea constitutes one of the most important aspects of atmospheric corrosion in coastal areas. Empirically, it is known that the effect of marine atmospheres extends principally some few hundred meters from the shoreline and decays rapidly further inland. As coastal corrosion rate depends on the concentration of chloride in the atmosphere, influence of wind and surf zone on the production of saline droplets and the decrease of the amount of these droplets from settling and impingement were discussed. The complexity of phenomena associated with marine atmospheric corrosion makes it difficult to devise a model that covers all scenarios.[12] With reference to the Table 6 of 37.9% or 31 number of dome location is between 1001m to 1500m. Whereas the distant dome is at 7270m from the coast.

Table 6: Distance From Coast.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	<500m	14	17.1	17.1	17.1
	501m-1000m	17	20.7	20.7	37.8
	1001m-1500m	31	37.8	37.8	75.6
	1501m-2000m	14	17.1	17.1	92.7
	>2000m	6	7.3	7.3	100.0
	Total	82	100.0	100.0	

The overall condition of the dome in the coastal city area has a balanced result between the dome that is good and conditionally dilapidated with 45.1% and 41.5% respectively or by 37 and 34 respectively, while the remaining 11 domes is fair. The histogram in Figure 2 shows a balanced graph on the right and left with the mean value 1.96 and the standard deviation of 0.936.

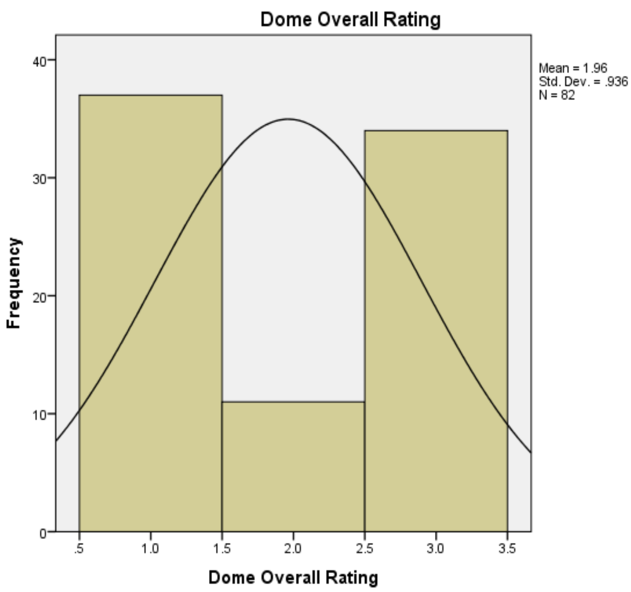

Fig. 2: Dome Overall Rating.

Chi-squared test was conducted to analyse the correlation between dome condition with its age, the correlation between dome condition with coastal distance, the correlation between dome condition with sea level height, the correlation between dome condition and material finishes and the correlation between dome condition and dome size. The contingency coefficient is derived from chi-square (χ2, pronounced 'kie' to rhyme with 'tie'). First, it is necessary to explain how χ2 is calculated for different sized tables. It is based on the squared difference between the observed (O) and the expected (E) frequencies, divided by E, for every cell of a contingency table. This calculation provides an indication of how much each individual cell contributes to the overall association between the variables [13]. The total $\chi 2$ value for all cells provides the basis for a measure of overall association. If E and O are the same in all cells of a table, there will be no association between the variables. The extent to which they are different indicates some kind of association. The larger the total $\chi 2$, the stronger is the association. The equation is

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

$\chi 2$ can be calculated for tables of any size. Now that we can calculate $\chi 2$, we can return to the contingency coefficient. This is the most basic measure of association between two nominal-level variables. It is derived directly from the total $\chi 2$ in a contingency table. However, as the magnitude of the total $\chi 2$ can be influenced by the table total, the $\chi 2$ has to be modified to take this into account. Hence, the equation for the contingency coefficient (C),

$$C = \sqrt{\frac{\chi^2}{\chi^2 + N}}$$

Contingency coefficient, it is necessary to outline the convention to be followed in the rest of the result for indicating the strength of an association, based on the value of the coefficient as shows in Table 7.[13] This convention will be used for all measures of association.

Table 7: Contingency Coefficient Schedule.

Score	Strength of an Association
0.00	None
0.01–0.09	Negligible
0.10–0.29	Weak
0.30–0.59	Moderate
0.60–0.74	Strong
0.75–0.99	Very strong
1.00	Perfect

Result from this analysis, we will look at the correlation between the dome conditions and the factors previously stated. The results of this analysis can be seen on the contingency coefficient value in following Table 8: Symmetric Measures Dome Overall Rating * Dome Age (Decades), Table 9: Symmetric Measures Dome Overall Rating * Distance From Coast, Table 10: Symmetric Measures Dome Overall Rating * Dome Elevation From Mean Sea Level (MSL), Table 11: Symmetric Measures Dome Overall Rating * Dome Materials and Table 12: Symmetric Measures Dome Overall Rating * Dome Sizes (Diameter in Meter).

Table 8: Symmetric Measures Dome Overall Rating * Dome Age (Decades).

		Value	Approximate Significance
Nominal by Nominal	Contingency Coefficient	.660	.000
	N of Valid Cases	82	

With refer to Table 7 contingency coefficient schedule, there is a strong correlation between the dome's overall rating and the age of the dome where the contingency coefficient score at the value of 0.660 as shown in table 8. Likewise, with Table 9 where the correlation between dome overall rating and distance from the coast which has a 0.661 score or can be translated as a strong correlation.

Table 9: Symmetric Measures Dome Overall Rating * Distance From Coast.

		Value	Approximate Significance
Nominal by Nominal	Contingency Coefficient	.660	.000
	N of Valid Cases	82	

Whereas for the correlation between dome overall rating and dome elevation from MSL is moderate status with score contingency coefficient at 0.419 and approximate significance at 0.026 as shown in Table 10.

Table 10: Symmetric Measures Dome Overall Rating * Dome Elevation From MSL

		Value	Approximate Significance
Nominal by Nominal	Contingency Coefficient	.419	.026
	N of Valid Cases	82	

Table 11 represents the Symmetric Measure results involving dome overall rating and material dome finishes. With the value of contingency coefficient at the 0.522 and approximate significance at 0.001, put the material factor as a moderate correlation.

Table 11: Symmetric Measures Dome Overall Rating * Dome Materials

		Value	Approximate Significance
Nominal by Nominal	Contingency Coefficient	.522	.001
	N of Valid Cases	82	

The same situation applies to the factor dome size and dome overall rating shown in table 12, where the score of the contingency coefficient at the 0.441 and the approximate significance at the 0.032 value. This value places the size dome factor as a moderate.

Table 12: Symmetric Measures Dome Overall Rating * Dome Sizes (Diameter in Meter).

		Value	Approximate Significance
Nominal by Nominal	Contingency Coefficient	.441	.032
	N of Valid Cases	82	

DISCUSSION

Comparatively, based on the results of all 82 inspected for its dome structure, found dome construction in the study area began as early as the 1960s and increased its construction in the next two centuries of the 1970s and 1980s. While in 1990 to 1999, the construction of the dome was reduced by only five. In the year 2000 up to current shows an increase in building construction with dome especially government and commercial office buildings. The building age has indeed a significant correlation with the condition of the building element. This situation is supported by the analysis of data that has been made which gets value in a strong correlation between the two factors.

Distance dome with coastal also has strong collation with the condition of a building. Areas closest to the shoreline (~ 400 m to 600 m), using published data by Feliu et al, it was shown that the decrease of the corrosion rate with distance from the sea is represented well by a simple exponential relationship. This condition will slightly affect the building condition around. In this study the nearest dome distance is at distance of 55m and most of the other dome is located at 1001m to 1500m.

The dome position of the MSL level has moderate correlation and does not affect the condition of the building. There is a dome at a high level having dilapidated condition compared to the lower dome that has a better condition. Similarly, the correlation between dome condition with dome size has moderate status. Both factors have Contingency Coefficient at the rates of 0.419 and 0.441.

The average material dome finishes used have a warranty period of at least 10 years. Material Metal Zink, the highest choice of dome finishes in the study area, has a paint surface and coated steel substrate on two variants, i.e. 10/25 years and 20/25 years. This factor contributes to moderate correlation between material dome finishes and building conditions. However, the Contingency Coefficient at the 0.522 level is nearly to strong correlation.

CONCLUSION

The dome structures available in coastal city of Kota Kinabalu Sabah was assessed using the software developed with a total of 82 dome of 24 building having dome structures available was assessed for its condition. Among all 84 domes, only 34 building were found to have dilapidation condition while the other 37 has no visible defects and the rest in fair condition. The results of from the conduction of building inspection showed that these structures have minor defects which indicates that the dome structures in coastal city of Kota Kinabalu Sabah are in balanced result between the dome that is good and conditionally dilapidated. The age and distance of the dome location of the coastal area contribute to a substantial factor in the dome condition.

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