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ARTICLE

Comprehensive Investigation into the Menace of Roof Collapse in Tamale and the Way Forward

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ABSTRACT

There is a perpetual problem of partial or complete roof collapse within the Tamale Metropolis and other parts of Ghana. This has become an issue of grave public concern since this menace affects both public buildings of all kinds (schools, offices, churches, mosque etc.) as well as domestic buildings.

This research sets out to conduct comprehensive investigations into the nature of roof failures, causes, and effects and then propose remedial actions towards stemming the tide.

The study employed the use of roof construction affirmation surveys, questionnaires, interviews and focus group discussions. Relevant information synthesized indicates that the roof type, construction materials, building type and environmental conditions are crucial causative factors.

Major consequences of roof failures include damage to personal belongings and exposure to inclement weather conditions, the psychological trauma victims are subjected and pressure on incomes and living conditions as a result of the cost of repair or replacement of the roofs.

It is recommended that expert advice be sought in checking maintenance requirements of existing roofs in the study area and also during the design and construction of new roofs. Tree planting programmes for this heavily deforested region should be encouraged. The use of green timber for roof construction must be replaced with well-seasoned ones. Proper construction detailing and placement openings buildings should be done so that wind flow during a windstorm is optimized.

1. Introduction

The roof is the second on the foundation as the most important component to a building. It is the part of the building that offers protection against elements of the weather. It is that component of a building which is most associated with the concept of shelter. A homeless person is usually described as someone without a roof over his or her head [1].

There are incessant reports in the media year in year out on roof failures as a result of rainstorms throughout the country and Tamale in particular. The consequent

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effects on victims in the study area of Tamale is particularly prevalent at the beginning and end of the rainy seasons which spans from April to September

Generally, the design of a roof for a building should be made after due consideration to its structural function of spanning the space and helping to control the climatic conditions within it [2].

Evolution in design and construction has birthed various forms of roof typologies. Generally, roofs can classify into two types main on the basis of slope: flat and pitched roofs. Those with pitch (angles) not exceeding 10˚ are classified as flat, while the ones with a higher pitch (angles) are referred to as pitched. Flat roofs may be susceptible to aquaplaning, however in pitched roofs there is improved drainage thus their popularity in most climates. Pitch roofs are less prone to leakages and even where minor holes occur, the water can still easily drain over them [3].

Roofs can be affected by elements of the weather and can be subjected to failure. Roof failure refers the situation whereby a roof is no longer capable of performing any of its required functions. These failures could be either structural or environmental. The ultimate and more easily noticeable type of structural failure is roof collapse while environmental failure manifests itself in the form of reduced ability to act as barrier to heat flow from the atmosphere to the building interior" [4-6]. Other indices of roof failure include leakages, condensation and rusting or corrosion [7].

2. The Study Area

Tamale Metropolitan Area refers to the geopolitical limits of the Tamale Metropolitan Assembly of Ghana. It is the capital of Northern Region and has an area of 922 km^2, [9,10] as well as a total population of 371,351 [9].

The Tamale Metropolis is one of the 26 districts in the Northern Region. It is located in the central part of the Region and shares boundaries with the Sagnarigu District to the west and north, Mion District to the east, East Gonja to the south and Central Gonja to the south-west. The Metropolis has a total estimated land size of 646.90180 sqkm (GSS, 2010). Geographically, the Metropolis lies between latitude 9º16 and 9º 34 North and longitudes 0º 36 and 0º 57 West [13].

Tamale lies on 195m above sea level Tamale has a tropical climate. There are two seasons in a year: the rainy (April-September) and the dry seasons (October-March). During the dry season, (Mid November to end of January) dry winds from the Sahara blow across the region. In Tamale, the average annual temperature is 27.9 °C. While the annual precipitation records about 1111 mm / 43.7 inches per year. On the average, September is the most humid and December the least humid month. The average annual percentage of humidity is: 47.0%. The windier part of the year lasts for 8.0 months, from December 12 to August 10, with average wind speeds of more than 6.1 miles per hour. The windiest day of the year is January 14, with an average hourly wind speed of 7.7 miles per hour. The calmer time of year lasts for 4.0 months, from

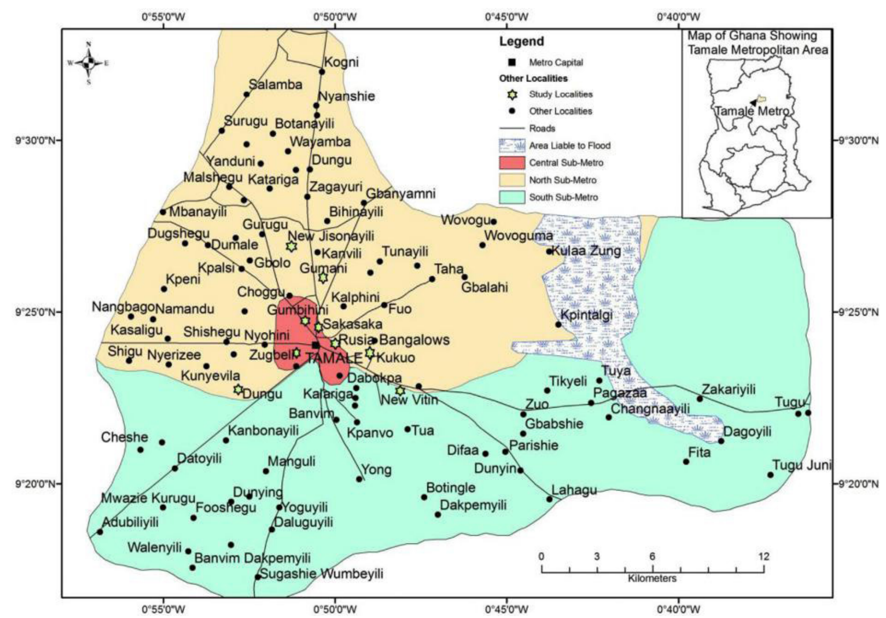

Figure 1. Map of the Tamale Metropolitan Area.

Source: Yakubu et al, 2014

August 10 to December 12. The calmest day of the year is September 23, with an average hourly wind speed of 4.6 miles per hour [14].

3. Literature Review

The roof is the component of the building that protects it from elements of the weather such as rain, wind and the sun. At the same time, it is also the element most subject to abuse [4]. Roofs are subjective to their own dead loads and live loads from winds, snow, rain etc. these loads need to be borne adequately by the structural members and covering. Contemporary design and construction methods have resulted into various techniques and roof patterns. Basically, roofs are classified according to their slope as either pitched or flat. Gradients of less than 10˚ are deemed flat roofs, while those above 10˚ pitched roofs. The susceptibility of the former to leakages is well known. The latter on the other hand offers improved drainage thus are seen as are more leakage proof. Gable roofs form the most dominant type of pitch roof.

The most determinants in the selection of roofs include, form of building, span, cost and the visual effect of the building.

The fascination with having a covering overhead any structure as shelter is as primitive as humankind. The quest for safety and security through a roof over their heads perhaps drove early man to dwell in caves and hollowed out trees [16]. These provided innate protection from inclement weather. Man-made roofs later evolved from natural and unnatural sources in recent times. For instance natural sources such as thatch and bamboo obtained from plant sources emerged. With technological innovation, roofs are now made from various materials including metals, clay, concrete, plastics, glass etc.

The susceptibility of roofs generally to elements of the weather and to partial or total failure is not in doubt. Failure in a roof is said to have occurred when it is no longer able to perform its designed tasks. Structural and thermal factors are the main categories of roof failures. Distinguishably total roof collapse is the most perceptible form of roof failure. Conversely, failure in terms of thermal conditions is expressed in the form of curtailed capacity of the roof to impede the entry of weather elements from the external environment into internal spaces [5-7]. Added indications of roof failure involve rust, sagging, leakages and decayed timber members [8].

Durability and the efficacy of a roof are the criteria used to evaluate its capability and capacity. Majority of failures in roofs happen around connection points such as nailed or bolted joints. These deficiencies during the construction stage are further aggravated by gradual depreciation of the components. Lack of consideration for details like factors of safety and tolerance could result in failures in roofs. The influence of winds, improper maintenance, fire, deficient quality components and poor works superintendence practices in roof failures deserve mention. Subsequently grave socio - economic ramifications including loss of lives and property usually ensue from roof failures [15,16].

Reports are rife in both the traditional and social media every year in Tamale about roof failures. This imposes severe suffering and deprivation on a community that is plagued with poverty and need. Therefore strenuous attempts should be made in order to ameliorate this situation.

4. Information (Data) and Procedures

The Roof Construction Affirmation Process

The roof design affirmation process involved undertaking random surveys on the media reported and unreported cases of collapsed and ripped off roofing systems in the Metropolis, peri-urban and rural parts of the study area over a two year period (2018-2020). The outcome of these studies suggested that the persisting roof failure does not only affect aged roofs but also the recently constructed.

The investigations also divulged that the unending roof failures affect all manner of buildings e.g. single and multistory residential buildings, schools, offices, churches, mosques and warehouses.

Total collapsed or partial rip off was recorded in most of the roof systems. Pitched roofs with sawn timber as rafters and purlins mostly formed the structural unit. Roof coverings were many and varied including corrugated galvanized or aluminum sheet (pigmented and non-pigmented) and thatched roofs.

Other methods employed in the data gathering comprise structured questionnaires, interviews and focus group discussions. Relevant data sought included construction materials of roofs, materials used for structural members, regularity of maintenance, roof age, culture of maintenance and possible causes of failure. The attendant ramifications on the lives and livelihoods of victims were also interrogated.

In total, 260 buildings across the Metropolis were surveyed. These comprised of domestic (75%) academic institutions (10%) religious (5%) warehouses (3%) and others (7%).

The age distribution varied from the recently built to a peak of (fifty) 50years. Buildings surveyed also constituted the ones in good condition and the rest that suffered some partial or complete collapsed. The affected buildings with defects were investigated and included in the analysis of results. However, the unaffected were repudiated.

Table 1. Characteristics of buildings surveyed

Type of building	Roofing members and covering	Age of building	Purpose	Sample size
Domestic	Timber rafter and purlins with pigmented and non-pigmented galvanized or aluminum sheets and thatch roofs with off-cut timber/tree branches	From 6 months-50 years	Residential, with some commercial functions	75%
Academic	Timber rafter and purlins with galvanized and aluminum sheets	From 1- 30 years	Teaching, learning and research	10%
Religious	Timber rafter and purlins. In some cases metal trusses with pigmented and non-pigmented galvanized or aluminum sheets	From 6 months-50 years	Worship	5%
Warehouses	Mostly metal trusses with pigmented and non-pigmented galvanized or aluminum sheets	From 1- 10 years	Storing manufactured goods and farm produce	3%
Others	Timber rafter and purlins, metal trusses with pigmented and non-pigmented galvanized or aluminum sheets	From 6 months-50 years	Offices, commercial buildings, small scale industries guest houses and hotels.	7%

5. Results and Discussion

5.1 Results of Quantitative Study

The types of failures observed during this study can be broadly divided into two, collapse and non-collapse. Collapse entails the complete removal of the entire roof from the building, while in non-collapse failure the roof is still in place but may suffer one problem or the other that inhibits it from maximum performance. Such failures include corrosion, leakage, exposed laps, tearing off of sheets, rafter damage, detached nails, rotten timber, bowing and disfigured roofs. The results of the study are shown in Figure 2.

Form the results of the roof construction affirmation process and the other methods employed i.e. structured questionnaires, interviews and focus group discussions, it is now known that the recurring roof failures affect all building typologies comprising domestic dwellings, academic, offices, warehouses and others.

The foremost mainspring of roof rip off is wind emanating from storms. This is exasperated by substandard materials and components as well as bad artisanship. In a lot of instances, infirm bands of steel were applied as ties between walls and the timber structural roof frame. The irregular surface of the walls on which the timber plates sit coupled with the infirm steel bands exposes the structure to much stress. Additional stresses/loads from storms for example can easily cause failure of these roofs.

These failures manifest as partial (74%) or complete (26%) failures. They can also be classified into rainstorm damaged (23%) and those that suffer gradual deterioration as a result of poor maintenance (76%). Pitched/gable roofs with timber structural members and pigmented and non-pigmented galvanized iron and aluminum coverings constituted the majority (94%). A small percentage of (4%) thatch roofs and about (2%) made of composite roofs i.e. concrete clay tiles, shingles etc. were also recorded.

Factors that were identified as the main causes of partial collapse included the following corrosion (15%), opening of exposed laps (7.8%), leakage (18%), rotten timber (11.3%), and damage to rafters (8.8%), detached nails (10.8%), bowing (10.1%) and the disfigured roofs (7.2%).

5.2 Construction Materials for Roofing

A total of 91% of the roofs under this study were constructed with timber structural frame covered with pigmented and non-pigmented galvanized iron and aluminum sheets, (4%) thatch roofs, (3%) concrete and, the rest including clay tiles and shingles account for up to (2%).

Though thatch roofs have been used historically in this location as a result of their suitability for the climate and availability, they are currently restricted to rural parts of the Metropolis. Bush poles (planted at the central point in the space as well as framing for the conical shaped rooms) are predominantly used. Concrete roofs which usually form a composite with the timber framed roofs as verandahs, water tank towers, roof terraces etc. also exist. The casting methods of these concrete roofs render them highly liable to leakages. The high heat conduction capacity of aluminium may be considered unsuitable for this climate; however its equally high resistance to corrosion makes it a preferred choice.

Timber is the material most frequently used for rafters and roof trusses. In the case of small to medium spans it is considered comparatively cheaper and very familiar to artisans and workmen. The spans and altitude of large buildings such as warehouses require higher strength and stability hence steel trusses are applied.

Details of this distribution are illustrated in Figure 2:

5.3 Identification of Potential Causes

5.3.1 Roof Construction Affirmation Process

Diligent examination through the roof construction affirmation process unveils major causative factors of the recurrent menace of roof collapse in the area of study.

5.3.2 Ecological Damage

The difficulty with the incessant pulling-off of roofs can largely be associated with the ecological damage. Trees and vegetation in the vicinity of majority of buildings struck by this menace were largely bare. As a result roof surfaces take the full impact of wind loads; more often than not they are unable to withstand the wind pressure and eventually collapse. In most cases these trees which act as windbreaks were removed to make way for the new construction. It would have been prudent to restore the vegetation with rapid growth varieties. The surveys however revealed otherwise.

5.3.3 Roof Layout Issues

Results of the random surveys of roof construction affirmation process, carried out by this study reveals that more than 95% of roofs construction are predominantly executed based on experiential knowledge of artisans, instinct and commonsensical methods instead of being based on the scientific approach.

• Deficient erection was noted to be one of the principal causative factors of roof failures in the random surveys. For instance, artisans determine the size of structural timber members without recourse to codes and structural calculations.

• Additionally, owing to the prohibitive prices of adequate grade timber members for the structural frame, prospective builders resort to lower grade and undersized structural timber members.

• The roof structures formed from these timbers are usually not built to standard design details and in such situations the whole construction is left to the discretion of the carpenter to decide on the design solutions. The tiny structural lumber sizes renders these roofs vulnerable to destruction through forces of suction as a result of wind storms.

• The concept of rigidity of the triangular form in structures was not very apparent. Timber studs which could otherwise be used as straps to hold back the outspread at the base of rafters however were fastened to wall plates at uneven intervals thus making the entire structure of the roof prone to lifting during windstorms.

5.3.4 Faulty Erection and Works Superintendence Methods

The random surveys in the roof construction affirmation process further unveiled the following:

• Inadequate knowledge on the part of artisans e.g. instances were observed in which the timber structural frame was structurally sound, however owing to bad erection such as poor/inadequate fastening of the timber structural frame to the blockwork/concretework of

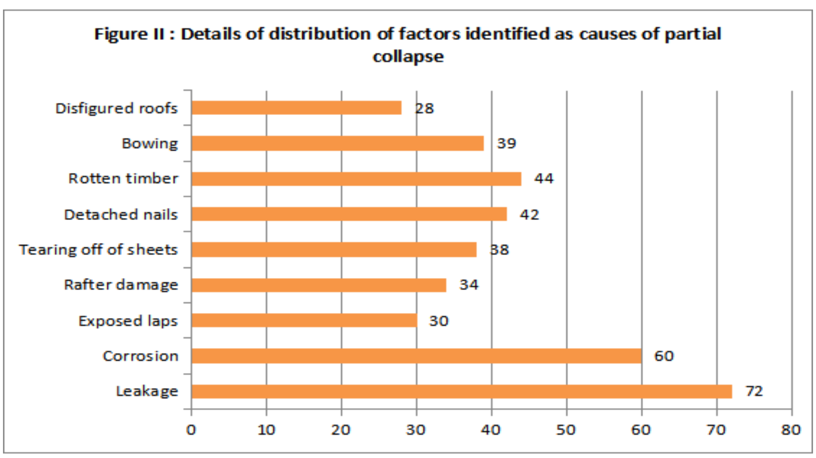

Figure 2. Details of distribution of factors identified as causes of partial collapse

buildings. The roofs are thereby rendered deficient and can become vulnerable to windstorms.

• Purlins not adequately fastened to rafters and top chords of trusses. Purlins were observed to be pulled off inclusive of metal coverings while the remainder of the roof structure was still intact. Rafters were not also adequately fastened to wall plates. Some ripped off roofs with wall plates intact were also observed. Poor fastening techniques of sheet coverings especially at high risk joints and junctions of roof planes exposed these coverings to being pulled off. Nailing of joints in the course of construction of roofs with no due regard to the margins renders the nails not deeply rooted enough to prevent the roofs from being lifted off during windstorms

• The expanse of laps at the ends of roof coverings was also found to be rather insufficient. This allows driving rain to bring in moisture to timber structural members causing their decay and subsequent leaking and damage of the entire roof structure.

• There is total absence of superintendence by consultants and professionals. Prospective builders prefer to deal directly with artisans due to the poor building controls. Majority of erected roofs of this kind are defective in many regards and are highly prone to damage. Roof coverings are mostly manufactured by industrial processes. However the requirements and instructions of these manufactures are usually not complied with. Not complying with the recommended gradients and gauges of coverings result in deficiencies such as deterioration of roofing members hence leakages.

5.3.5 Poor Culture of Maintenance

The poor culture of maintenance in the study area is well known. The roofing regimen is not spared this menace. Prolonged exposure to inclement weather brings about decay and damage to roofing members and coverings leading to leakages and crumbling of roofs. Without a proper maintenance regimen, repercussions of gradual decay and coincidental damage to roofs give rise to the eventual damage.

5.3.6 Economic Implications of Roof Collapse

The projected cost of construction of new roofs is normally estimated to be up to 20% of the entire cost of construction. On the other hand, replacement cost of damaged roofs can reach up to 40% [17]. Considerable losses take place with the occurrence of failures in roofs. Firstly, the cost of replacement and also the cost of damage to items within the buildings such as stationery, furniture and other prized possessions. This has profound implications on the quality of life, education and livelihoods in general.

Information on the quantum of losses to victims is not easy to come by. This is as a result of the fact that most victims do not keep records of their losses. Also, low property and other insurance product uptake renders the availability of these records very challenging. In some instances Government intervention through the National Disaster Management Organization (NADMO) is not indexed to the quantum of loss.

In qualitative terms, the collapse of roofs subjects the affected people to vagaries of the weather. The burden associated with cost of replacement constitutes a huge financial burden on them. Furthermore, the hazards and perils to their health and psychological wellbeing cannot be over emphasized.

In view of this, the study will venture into estimating the quantum of losses to victims of roof collapse.

Assume

▪ a yearly rate of roof collapse of 0.5 buildings per 1000

▪ total number of houses 965,000

▪ 94% of the total number of houses typical angled roofs

Hence

▪ On a yearly basis, up to about 325 buildings experience roof collapse.

Assume

▪ Current estimated cost of replacement (structure and covering) is GHS¢ 20,000.

Then

▪ Total cost of replacement equals GHS¢ 6,650,000 yearly. This constitutes an enormous financial burden in an area where incomes and earnings are relatively very low.

▪ Estimated work days of up to 65,000 in total are lost. This works out to around 90 work days for every replacement job.

▪ The environmental consequences in terms of the number of trees cut for replacement of the structural frames of these buildings can also be considered as dire. More than 700 logs from forests in southern Ghana are harvested for this purpose.

6. Conclusions

By way of the roof construction affirmation investigation coupled with quantitative and qualitative surveys, it was found that various kinds of roofs including flat roofs, gable/hipped etc. are all found in the study area. However hipped roofs dominate.

Factors such as span, strength and durability, cost and aesthetics among others are the principal reasons for the selection of roof type. Timber framed structures with pigmented and non-pigmented galvanized/aluminium coverings are the main construction materials. Roof collapse can also be categorized as partial and complete. The partial variant is expressed in the form of rust/corrosion, sagging, disfigurement and leakages.

Ecological factors like the absence of trees and vegetation as well as design and construction issues, poor works superintendence, poor artisanship and weather elements can be attributed to the gradual decay and deterioration in partial roof collapse.

Notwithstanding the fact that the exact cost implications of roof failures are not easily known, attempts have been in this investigation to estimate the monetary, labor and other implications such as the hazards and perils on victims health and psychological wellbeing.

7. Recommendations

The recommendations are structured as follows:

• General recommendations

• Particular recommendations of deficient construction practices

7.1 General Recommendations

We recommend that existing roofs be checked for maintenance issues such as rotten timber, open lapped ends, leakages torn parts in the coverings. This will ensure that problems are detected early enough and building owners alerted to take action. This enforcement measure could be taken up by District engineers and their teams. Appropriate maintenance culture should also be initiated, cultivated and enforced by local authorities and even the security and disaster management bodies.

The study area is replete with depletion of forests and trees at building sites without replanting. It is therefore recommended that rapid growing local trees like acacia and neem be applied in a massive replanting drive generally and at building sites in particular.

Application of well cured timber in roofing should be encouraged. Where this is not available, fresh cut timber must be allowed periods of at 30 days to achieve sufficient curing before the covering materials are placed.

The necessity of proper fastening of the roof to the concrete/blockwork structure is crucial. Currently artisans apply 6 mm diameter mild steel cords. It is recommended that these fasteners should measure up to 7.5 mm diameter and be spaced at least 600 mm centre to centre. Connections and junctions that are subject to the most stress and strain including ridgelines, overhangs and valleys should also receive the 75 mm steel bands at even more closer intervals of 450 mm.

Proper artisanship is pertinent to the right functioning of any roof. Enforcement of building codes and bye-laws should be taken seriously by local authorities. Their Building control function needs to be stepped up. This will ensure that artisans and prospective building owners are held to the codes and building regulations. Consequently disasters relating to roofs will be stemmed. Artisans should also receive re-training so that they can unlearn their obnoxious methods and relearn current best practices.

Table 2. Recommendations of deficient construction practices

Item	Deficiency identification	Recommendation
1	Uncoupling of rafter, wall plate and ceiling joist.	These members must be tied together to form one fixed triangular rigid frame.
2	Rafter length increasing connections using timber off cuts	Mild steel plates of at least 10mm thickness should be used instead of off-cuts.
3	Rafters and bottom chords of trusses fastened to protruding reinforcement bars	These should be done right-angled mild steel plates connected with bolts and nuts
4	Off-centre pattern of timber structural members in trusses and rafters	Well-proportioned and balanced grid like patterns are encouraged
5	Gable ends of walls grooved and purlins fixed with concrete /mortar grout	Purlins should be fastened to walls by horse-shoe shaped metal clips of about 750 mm thickness.
6	Attachment of purlins to rafters and top chords of trusses without provision against slippage.	Provision of angular shaped timber cuttings to the underside of these attachments to act against slippage.
7	Joined rafters at the ridge not strengthened in the triangular shape underneath	Introduction of vertical and cross bracing between rafters recommended

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ARTICLE

Experimental Shear Study on Reinforced High Strength Concrete Beams Made Using Blended Cement

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Span to depth ratio

ABSTRACT

With the increased application of High Strength Concrete (HSC) in construction and lack of proper guidelines for structural design in India, behavioral study of high strength concrete is an important aspect of research. Research on the behavior of HSC reinforced beams with concrete strength more than 60 MPa has been carried out in the past and is still continuing to understand the structural behavior of HSC beams. Along with the many benefits of the high strength concrete, the more brittle behavior is of concern which leads to sudden failure. This paper presents the behavior of reinforced HSC beams in shear with considering the effects of various factors like shear reinforcement ratio, longitudinal reinforcement ratio, l/d ratio (length to depth ratio), etc. Ten numbers Reinforced Concrete Beams of various sizes using concrete mix with three different w/c ratios (0.46, 0.26 and 0.21) were cast for shear strength assessment. The beams were tested in simply supported condition over two fixed steel pedestals with load rate of 0.2 mm/minute in displacement control. Mid-point deflection was measured using LVDT. A comparative analysis of theoretical approaches of Euro code, extension of current IS code up to M90 and the experimental data was done to understand the behavior of beams. Shear capacities of beams without any factors of safety were used to assess the actual capacities and then was compared with the experimental capacity obtained. Results of this study can be used in the design of high strength concrete and will be more reliable in Indian continent as the regional materials and exposure conditions were considered.

1. Introduction

The advancement of concrete technology has led to the production of higher grades of concrete. High strength concrete offers far better engineering properties like compressive strength, tensile strength, durability, modulus of elasticity and overall better performance when compared to the conventional concrete [1,2]. However, high-strength concrete is more brittle in nature because cracks in this material do not always follow the aggregate-

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hardened cement paste interfaces due to the improved interfacial bond strength and interfacial transition zone of high-strength concrete but may cut right through the hardened cement paste and even the aggregate particles leading to rapid propagation of the cracks and sudden or sometimes explosive failure of the concrete. Because of this problem, many structural engineers hesitate in using high-strength concrete, despite its obvious advantages. Research on the behavior of HSC beams with concrete strength higher than 55 MPa has been carried out in the past and is still continuing, to understand the behavior of HSC beams [3,4].

The shear failures of reinforced concrete beams can be sudden, brittle, and non-ductile. The mechanisms of shear transfer in reinforced concrete structures are complex. However, the understanding of shear behaviour and failure modes has improved significantly in recent years. All structural elements depend on concrete to resist a component of the shear force applied to them. It is therefore important that the design equations that are used by structural engineers to evaluate the shear strength of beams were also applicable to members made with high strength concrete. The failure of the beam is governed by the crushing of the compression struts between the cracks, or by the crack slip. Generally, for a normal strength concrete beam, the crushing of the concrete governs the beam failure. In a high-strength concrete beam, the struts are able to carry more compressive stress, and failure is most likely initiated by the crack slip. Diagonal cracks are the main mode of shear failure in reinforced concrete beams located near the supports and caused by excess applied shear forces. Beams fail immediately upon formation of critical cracks in the high-shear region near the beam supports. Whenever the value of actual shear stress exceeds the permissible shear stress of the concrete used, the shear reinforcement must be provided. The purpose of shear reinforcement is to prevent failure in shear, and to increase beam ductility and subsequently the likelihood of sudden failure will be reduced [5].

Piyamahant (2002) showed that the existing reinforced concrete structures should have stirrup reinforcement equal to the minimum requirement specified the code. The theoretical analysis shows that the amount of stirrup of 0.2% is appropriate. The paper concluded that small amount of web reinforcement is sufficient to improve the shear carrying capacity. The study focused on the applicability of the superposition method that used in predicting shear carrying capacity of reinforced concrete beam with a small amount of web reinforcement at the shear span ratio of 3. Also the failure mechanisms were considered when small amount of stirrup used [6].

Sneed, and Julio (2008) discussed the results of experimental research performed to test the hypothesis that the effective depth does not influence the shear strength of reinforced concrete flexural members that do not contain web reinforcement. The results of eight simply supported reinforced concrete beam tests without shear and skin reinforcement were investigated. The beams were designed such that the effective depth is the variable while the values of other general parameters proven to influence the shear strength (such as the compressive strength of concrete, longitudinal reinforcement ratio, shear span-to-depth ratio, and maximum aggregate size) were held constant [7].

Various studies were carried out in the past to analyze and estimate the shear capacity of RCC beams. Studies revealed that ultimate strength of concrete beam in shear is significantly affected by the size of member and its effect cannot be ignored on diagonal cracking strength of reinforced concrete beams (similar in geometry) having 1:16 size range [8,9].

Similar findings were reported for shear strength of deep beams which have shear span / depth equal to 1.0 [10,11]. Complex nature of stress distribution mechanism in dowel splitting region of concrete beams which do not possess any stirrups (i.e. reinforcement for shear) still remains empirical in nature [12]. Concrete beams of higher grade are sensitive and significantly affected by the size effect. Reduction in ultimate strength in shear is related with maximum (centre to centre) spacing of different layers of the reinforcement in horizontal direction instead of overall depth of RCC beam [13].

This paper presents the behavior of reinforced HSC beams in shear with considering the effects of various factors like shear reinforcement ratio, longitudinal reinforcement ratio, l/d ratio (length to depth ratio).

2. Experimental Program

Concrete Ingredients

Coarse aggregate with a maximum nominal size of 20 mm was used as coarse aggregate and natural riverbed sand confirming to Zone II as per IS: 383-2016 was used as fine aggregate. Their physical properties are given in Table 1. The petrographic studies conducted on coarse aggregate indicated that the aggregate sample is granite. For both coarse aggregate and fine aggregate sample the strained quartz percentage and their Undulatory Extinction Angle (UEA) are within codal limits. The silt content in fine aggregate as per wet sieving method is 0.75 percent.

One brand of Ordinary Portland cement (OPC 53 Grade) with fly ash and silica fume are used in this study. The chemical and physical compositions of cement OPC 53 Grade, Properties of flyash and silica fume are given in Table 2. Polycarboxylic group based superplasticizer for w/c ratio 0.21, 0.26 and Naphthalene based for w/c ratio 0.46 meeting with requirements of IS: 9103 is used. Water meeting requirements of IS: 456-2000 for construction was used. The 3 days, 07 days and 28 days compressive strength of cement OPC 53 Grade were 37.00 N/mm^2, 47.00 N/mm^2 and 59.00 N/mm^2 respectively. The 28 days compressive strength of controlled sample and sample cast with flyash was 36.33 N/mm^2 and 29.34 N/mm^2 respectively, when testing was done in accordance with IS: 1727. The 07 days compressive strength of controlled sample and sample cast with silica fume was 13.26 N/mm^2 and 15.32 N/mm^2 respectively, when testing was done in accordance with IS: 1727.

Table 1. Properties of Aggregates

Property 20 mm		**Granite**		**Fine Aggregate**
		10 mm		
Specific gravity		2.80	2.78	2.61
Water absorption (%)		0.28	0.27	0.77
Sieve Analysis Cumulative Percentage Passing (%)	20 mm	95	100	100
	10 mm	3	64	100
	4.75 mm	0	4	91
	2.36 mm	0	0	83
	1.18 mm	0	0	64
	600 μ	0	0	34
	300 μ	0	0	8
	150 μ	0	0	5
	Pan	0	0	0
Abrasion, Impact & Crushing Value		21, 15, 18	-	-
Flakiness % & Elongation %		30, 24	-	-

Table 2. Physical, Chemical and Strength Characteristics of Cement

Characteristics	**OPC -53 Grade**	**Silica Fume**	**Fly Ash**
Physical Tests:			
Fineness (m^2/kg)	322.00	23000	410
Soundness Autoclave (%)	00.06	-	-
Soundness Le Chatelier (mm)	0.9	-	-
Setting Time Initial (min.) & (max.)	180.00 & 240.00	-	-
Specific gravity	3.12	2.21	2.19
Chemical Tests:			
Loss of Ignition (LOI) (%)	1.54	1.19	-
Silica (SiO_2) (%)	20.78	94.33	-
Iron Oxide (Fe_2O_3) (%)	3.99	0.77	-
Aluminium Oxide (Al_2O_3)	4.90	-	-
Calcium Oxide (CaO) (%)	61.71	-	-
Magnesium Oxide (MgO) (%)	4.18	-	-
Sulphate (SO_3) (%)	2.17	-	-
Alkalies (%) Na_2O & K_2O	0.59 & 0.61	-	
Chloride (Cl) (%)	0.03	-	-
IR (%)	1.30	-	-
Moisture (%)	-	0.47	-

3. Mix Design Details

In this study, the three different mixes ranging from w/c ratio 0.46 to 0.21 using granite aggregate were selected for determining short term mechanical properties of HSC. For each type of aggregate, three separate batches were prepared. The slump of the fresh concrete was kept in the range of 80-110 mm. A pre-study was carried out to determine the optimum superplasticizer dosage for achieving the desired workability based on the slump cone test as per Indian Standard. The mix design details are given in Table 3. The laboratory conditions of temperature and relative humidity were maintained during the different ages at 27±2 °C and relative humidity 65%. The specimens were taken out from the curing tank and allowed for surface drying before it is tested in saturated surface dried condition.

Table 3. Concrete Mix Design Details for study done

w/c	**Total Cementitious Content [Cement C + Flyash (FA) + Silica Fume (SF)] (Kg/m3)**	**Water Content (Kg/m^3)**	**Admixture % by weight of Cement**	**Fine Aggregate as % of Total Aggregate by weight**	**28-Days strength of concrete (N/mm^2)**
0.46	**362** (290+72+0)	170	1.00	35	45.72
0.26	**525** (400+75+50)	140	0.70	39	88.60
0.21	**750** (548+112+90)	150	1.75	35	97.76

4. Experimental Study on Reinforced Cement Concrete (RCC) Beams in Shear

Research on the behavior of HSC beams with concrete strength higher than 50 MPa has been carried out in the past and is still continuing, to understand the behavior of HSC beams in shear. The experimental data obtained from testing of beams in shear have been considered with a view to compare the ultimate strength of beams in shear to the capacity predicted by Eurocode EC: 02-2004. For a comparison to be made between the actual shear capacities and theoretical shear capacities, the theoretical shear capacities are calculated based on the same parameters as the actual beams tested. Eight numbers Reinforced Concrete Beams of different sizes with different depths and a/d ratios using concrete mix with three different w/c ratios (0.46, 0.26 and 0.21) were cast. The design details of beams are given in Table 4.

Table 4. Design Details of Beams

Sl. No.	Concrete Grade	B (mm)	D (mm)	d (mm)	a (mm)	Ast (mm^2)	Bar Details (HYSD)
1	M40	200	250	215	530	1030	2 Nos. 20 mm & 2 Nos. 16 mm
2	M80	200	250	215	530	942	3 Nos. 20 mm
3	M90	200	200	165	330	942	3 Nos. 20 mm

Where, B= width of the beam section

D= Total depth of the beam section

d= Effective depth of the beam section

a= shear span of the beam = 1/3 of clear span

Ast= Area of longitudinal tensile reinforcement

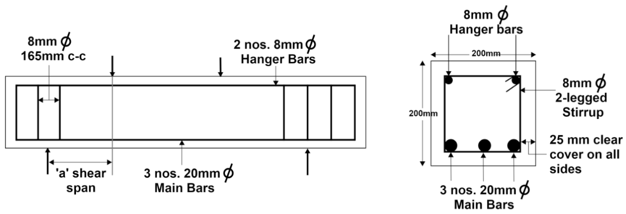

Figure 1. Sketch for design details of Reinforced Concrete Beam

The concrete mix used in RCC beams were as per mix design details given in Table 3. For Shear strength assessment, Flexural Testing Machine of 500 kN capacity having displacement rate control facility was used. The beam was placed in simply supported condition over two fixed steel pedestals to get the desired clear span. The loading setup was made for four points bending by placing a distributor beam over two roller supports at one-third span distance from supports (Figure 1). Keeping in view the specimen size to be tested and failure load, the loading was decided to be applied at the rate of 0.2 mm/minute in displacement control (Figure 2).

The three additional sets of concrete cubes were cast and tested at same day on which the testing was performed. The curing regime for both the RCC beams and concrete cubes were kept same to avoid the variation in compressive strength. The compressive strength obtained from the testing of these cube samples were used for checking the predicted capacities as per design codes.

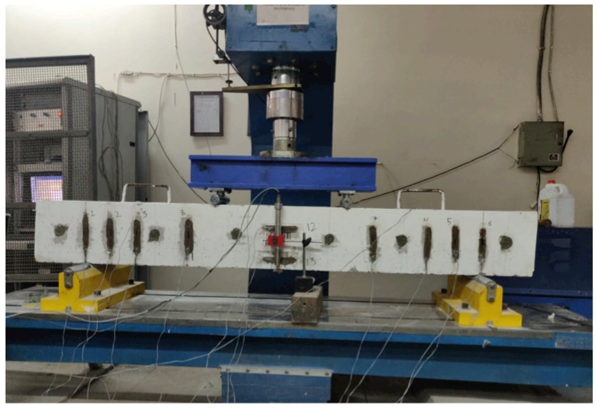

Figure 2. Test set up for Shear Strength of Reinforced Concrete Beams

4.1 Determination of Shear Capacity for High Strength Concrete

High-strength concrete has higher tensile strength hence a higher cracking shear can be expected. In various International codes of practice, the shear strength of a reinforced concrete beam is taken as the sum of the shear force that is carried by the concrete (Vc) and the web reinforcement (Vs). The term (Vc) in a diagonally cracked beam with web reinforcement represents the sum of three components: (a) dowel action resistance of the longitudinal reinforcement, (b) aggregate interlock resistance along the diagonal crack, and (c) the shear resistance carried by the uncracked concrete compressive zone. The term (Vs) represents the vertical component of the shear force carried by the shear reinforcement.

The Eurocode considers only shear force carried by the web reinforcement while the current IS code accounts for both steel as well as concrete in shear capacity. Since the IS code is applicable only upto M55 grade of concrete, to estimate the shear strength in this study IS approach was extended for high strength concrete. Comparison was done between shear capacity predicted by Euro code and extension IS approach to verify the applicability of the IS approach for higher strength concrete. In this study, comparison is also made by calculating shear capacity of RC beams using actual tested value of reinforcement yield strength (582 MPa) by adopting IS code method and shear capacity calculation by IS code method by restricting the value of reinforcement yield strength to 415 MPa. The equations used to determine the shear capacity are as follows:

Shear Capacity by Euro code

$$V_{Ed} = V_{Ed} = \frac{z\, fyd\, Asv \cot\theta}{s} \quad (1)$$

where, z = 0.9d

θ is taken as 45^0

f_{ywd} = yield stress of the web reinforcement

A_{sw} = cross sectional area of web reinforcement

S = spacing of the stirrups

Shear Capacity by IS approach extended upto higher grade

Concrete component based on semi empirical expression (SP 24, 1983).

$$Tc = \frac{0.85\sqrt{0.8\, fck}\,(\sqrt{1+5\beta}-1)}{6\beta} \quad (2)$$

where, $\beta = \frac{0.8\, fck}{6.89\, pt}$

$pt = \frac{100\, Ast}{bd}$

0.8 fck = cylinder strength in terms of cube strength

0.85 = reduction factor similar to $1\backslash\gamma_{mc}$

Steel component,

$$Vus = \frac{0.87\, fy\, Asv\, d}{sv} \quad (3)$$

where, f_y = yield stress of the web reinforcement

A_{sv} = cross sectional area of web reinforcement

s_v = spacing of the stirrups

The comparison of experimental shear capacity to shear capacity predicted by Euro code and IS approach is shown below in Table 5.

From the above table it could be noted that the values predicted from Euro code are much safer as it neglects the stress carried by concrete and considers only steel part. While Euro code uses actual yield strength of the web reinforcement, the current IS code restricts the value to 415 Mpa to be used in design even if the actual yield strength is higher than that. The values show that even if the extension of IS approach is to be used for higher grades of concrete the value of fy should be restricted to 415 Mpa as it will increase the factor of safety which is much needed as the shear failure is sudden or spontaneous in nature and there are no pre-failure symptoms. In case of lower a/d ratio, the ratio of experimental to predicted shear capacity is higher which makes it evident that the factor a/d plays an important role in determination of shear capacity of the member and should be incorporated in the design methods.

4.2 Effect of a/d Ratio on the Shear Design of High Strength Reinforced Beams

To see the effect of a/d ratio on the shear capacity of the high strength RCC beams, beams with different a/d ratios were tested keeping all other parameters constant.

From the above table it could be noted that the predicted shear capacities for all the three design with different a/d ratio is same while the experimentally obtained capacities are different for all the three designs. The results show that for lower a/d ratios the ratio of experimental and predicted shear capacities is very high as compared to when a/d ratio is higher. The experimental shear capacities for a/d ratios 2.42 and 2.83 are comparable while in case of a/d ratio of 2.01, a high experimental shear capacity was obtained. Therefore, the effect of a/d ratio should also be considered while designing the structures. The current method won't hold good when a/d ratio is lower than 2.0 while for a/d ratio higher than 2, the shear capacity decreases with increase in a/d ratio keeping other parameters constant. Over or under estimation of shear capacities can lead to various consequences in terms of loss of money and life.

4.3 Typical Failure Mode of RCC Beams

The beams failed due to widening and extending of cracks into shear zone, between the loading points (Figure 3 and Figure 4). As the intent of failure was to fail the beam in shear therefore flexural capacity was kept on the higher side to avoid any secondary stresses. Hence all beams failed in shear mode only and minor flexural cracks in the concrete were observed in flexural zone without yielding in steel reinforcement. The loading was continued till the major crack is observed in shear zone due to yielding of the stirrups.

Initially load was carried by both concrete and steel. With the initiation of minor carcks load gradually shifts from concrete to steel. Once the complete separation of the concrete takes place due to widening of cracks, the entire load is carried by shear steel reinforcement. When further load is increased stirrups yield and finally breaks to fail. Failure of the stirrups can be attributed to the large single crack in shear zone and sudden drop in the load-deflection or load-time graph.

Table 5. Comparison of Experimental Shear capacity to shear capacity predicted by Euro Code and IS approach

Beam Details	Code	Shear Capacity		Shear Capacity (kN)		Ve/Vp
		Concrete (Vc)	Steel (Vs)	Predicted (Vp)	Experimental (Ve)	
B1 M-40	IS Code with fy 415	49.07	44.84	93.91	145	1.54
	IS Code with fy 582	49.07	62.87	111.94		1.30
	Euro code	67.76	56.58	56.58		2.56
	Euro code (with concrete)	67.76	56.58	124.34		1.17
B2 M-40	IS Code with fy 415	49.07	44.84	93.91	139	1.48
	IS Code with fy 582	49.07	62.87	111.94		1.24
	Euro code	67.76	56.58	56.58		2.46
	Euro code (with concrete)	67.76	56.58	124.34		1.12
B1 M-80	IS Code with fy 415	49.83	56.03	105.86	150	1.42
	IS Code with fy 582	49.83	78.58	128.41		1.17
	Euro code	77.56	70.72	70.72		2.12
	Euro code (with concrete)	77.56	70.72	148.28		1.01
B2 M-80	IS Code with fy 415	49.83	56.03	105.86	189	1.79
	IS Code with fy 582	49.83	78.58	128.41		1.47
	Euro code	77.56	70.72	70.72		2.67
	Euro code (with concrete)	77.56	70.72	148.28		1.27
B1 M-90	IS Code with fy 415	43.74	43.00	86.74	234	2.70
	IS Code with fy 582	43.74	60.31	104.05		2.25
	Euro code	66.70	54.28	54.28		4.31
	Euro code (with concrete)	66.70	54.28	120.98		1.93
B2 M-90	IS Code with fy 415	43.74	43.00	86.74	230	2.65
	IS Code with fy 582	43.74	60.31	104.05		2.21
	Euro code	66.70	54.28	54.28		4.24
	Euro code (with concrete)	66.70	54.28	120.98		1.90

Table 6. Design Details of Beams

Sl. No.	Concrete Grade	B (mm)	d (mm)	Shear Span (a) (mm)	a/d ratio	Ast (mm^2)	Spacing of stirrups (Φ=8)(mm)
1	M90	200	165	333	2.01	942	160
2	M90	200	165	400	2.42	942	160
3	M90	200	165	467	2.83	942	160

Table 7. Comparison of Experimental Shear capacity to shear capacity predicted by Euro Code and IS approach with different shear span to depth (l/d) ratio

Beam Details	Span to Depth (a/d) ratio	Code	Shear Capacity		Shear Capacity (kN)		Ve/Vp
			Concrete (Vc)	Steel (Vs)	Predicted (Vp)	Experimental (Ve)	
B1 M-90	2.01	IS Code	43.74	43.00	86.74	234	2.70
		IS Code fy 582	43.74	60.31	104.05		2.25
		Euro code	66.70	54.28	54.28		4.31
		Euro code (with concrete)	66.70	54.28	120.98		1.93
B2 M-90		IS Code	43.74	43.00	86.74	230	2.65
		IS Code fy 582	43.74	60.31	104.05		2.21
		Euro code	66.70	54.28	54.28		4.24
		Euro code (with concrete)	66.70	54.28	120.98		1.90
B1 M-90	2.42	IS Code	43.74	43.00	86.74	163	1.88
		IS Code fy 582	43.74	60.31	104.05		1.57
		Euro code	66.70	54.28	54.28		3.00
		Euro code (with concrete)	66.70	54.28	120.98		1.35
B2 M-90	2.83	IS Code	43.74	43.00	86.74	156	1.80
		IS Code fy 582	43.74	60.31	104.05		1.50
		Euro code	66.70	54.28	54.28		2.87
		Euro code (with concrete)	66.70	54.28	120.98		1.29

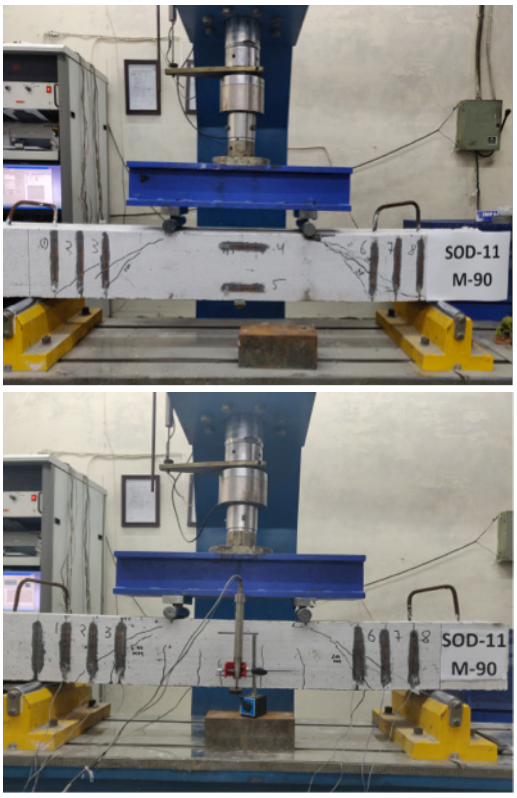

Figure 3. Failure Mode of RCC Beams

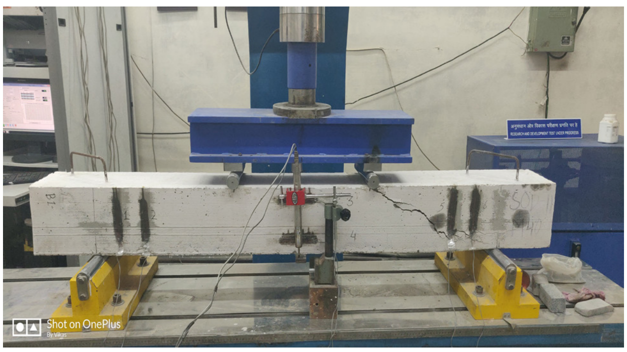

Figure 4. Failure Mode of RCC Beams in Shear

5. Conclusions

For an effective design the theoretical calculation of ultimate strength must be conservative or less than the ultimate failure load whereas for a sustainable design it should be conservative as well as the economically suitable. The design rules should provide similar level of conservativeness as well as sustainability for normal and high strength concrete. The values predicted from Euro code are much safer as it neglects the stress carried by concrete and considers only steel part. While Euro code uses actual yield strength of the web reinforcement, the current IS code restricts the value to 415 MPa to be used in design even if the actual yield strength is higher than 415 MPa. The values show that even if the extension of IS approach is to be used for higher grades of concrete the value of f_y should be restricted to 415 MPa as it will increase the factor of safety which is much needed as the shear failure is sudden or spontaneous in nature and there are no pre-failure symptoms. In case of lower a/d ratio, the ratio of experimental to predicted shear capacity is higher which makes it evident that the factor a/d plays an important role in determination of shear capacity of the member and should be incorporated in the design methods. The experimental shear capacities for a/d ratios 2.42 and 2.83 are comparable while in case of a/d ratio of 2.01, a high experimental shear capacity was obtained. Therefore, the effect of a/d ratio should also be considered while designing the structures. The current method won't hold good when a/d ratio is lower than 2.0 while for a/d ratio higher than 2, the shear capacity decreases with increase in a/d ratio keeping other parameters constant.

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ARTICLE

Inviting Nature into Academic Learning: Exploring the Possibility to Activate the Introvert Courts inside the University Buildings

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University campus

ABSTRACT

Established on peripheral sub-urban area of Sylhet city, Shahjalal University of Science and Technology is a public university well known for its beautiful natural environment and diversified landscape with green hillocks, waterscape, forests and biodiversity. But, the academic buildings of the campus were planned in an introvert way that the common void courts remain disconnected from the outside natural environment. Although designed with positive intention, most of the courts remain unused maximum the time of a year. As the campus natural environment is getting richer day by day and users prefer to spend more time in outside environment, it is high time to integrate nature into the academic learning. This research aims to explore the possibilities of these void courts to be incorporated with the outside natural environment to enhance joyful learning. A combined approach was adopted as research methodology consists of intensive physical survey, literature study, microclimate analysis, questioner surveys among the users, interviewing the field experts and selective national and international case studies. Lastly, a set recommendation has been proposed considering all the perspectives and issues that the research has identified.

1. Introduction

Sylhet is known as the "Green City" of Bangladesh for its distinct natural beauty. Each year the city attracts a huge amount of local inhabitants, investors and tourists to visit and settle here. The combination of natural hillocks, tea gardens and water bodies gives it a poetic outlook [1]. The Khadimnagar-malnicherra hilly area laid through the east-west direction adjacent to the city is the main belt of natural green consisting large area of reserve forest, tea gardens and rich biodiversity zones. The west corner of this natural belt is very close with the hilly forest zone of the Shahjalal University campus situated on the sub-urban territory of the city. This connection act as a major factor on campus green and biodiversity pattern that increasing day by day (Figures 1 and 2).

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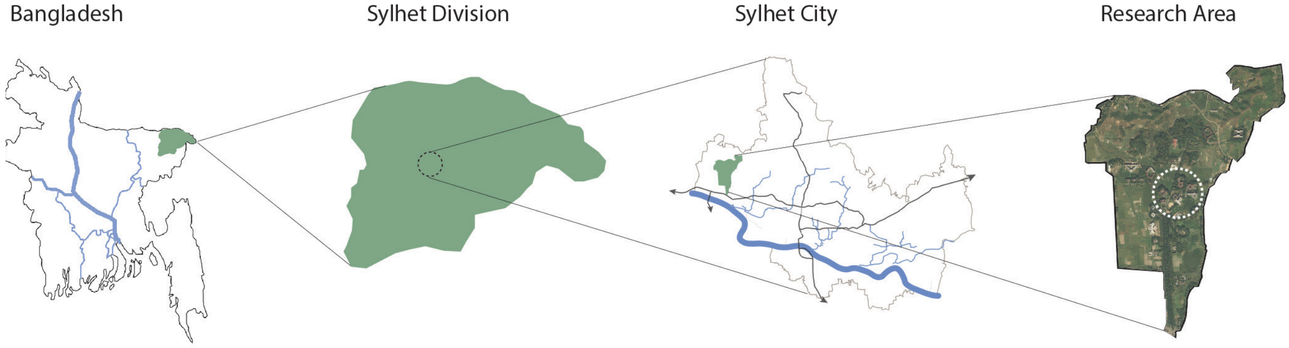

Figure 1. Location map and study area

Figure 2. Campus green cover change over time (Google Earth satellite view)

1.1 Study Area

Established in 1986, Shahjalal University of Science and Technology (SUST) has 320 acre land area counted as one of the major ecological hub in Sylhet city [2]. SUST has an image of green and natural sub-urban campus with a series of low height reserved hills with rich biodiversity that increasing every year. Only 9% is the built area inside the 320 acre campus where 29% has been occupied by the academic buildings built on the flat land which indicates the remaining vast open green space that encourage outdoor learning. There are a large number of courtyard buildings designed for academic, residential and recreation purposes. The campus has five academic buildings named as A, B, C, D and E n to hold the activities of 27 departments of 6 schools (Figure 3). Designed in an introvert manner, all academic buildings have one square shaped open to sky central courtyard surrounded by single loaded circulation corridor with classrooms, offices and supporting spaces. As the classrooms and offices started from the ground floor level, comfortable common gatherings zones are totally absent. Enclosed nature of the voids blocked the interaction possibility with outdoor nature (Figure 4). Despite some marginal uses and maintenance courtyards remain empty and unused maximum time of the year. Although few space modification and rearrangement occurs often in those buildings, courtyards somehow remain unnoticed; even sometimes used as temporary dumping space for broken furniture, goods or instruments. An irresponsible modification in the internal courtyard inside the library building caused darkness in the inner floors and permanent dependency on artificial lighting.

1.2 Courtyard: Significance and Modification

A courtyard can be defined as an open-to-sky enclosed space that surrounded by building or walls, have been designed and improved through the integration of social, cultural and environmental factors. Inducing both physiological and mental sensation of its users, courtyard acts as modifier of microclimate that improves comfort of the internal spaces in a building [3]. As an open and cluster space, courtyard fulfils various aspects as functions, leisure, social perspectives, or microclimatic and acoustic protection [4]. Almost all ancient civilizations of the world including Indus valley, Mesopotamia, Egypt, China along with Greek-roman classical period used courtyard in their built forms as prominent design feature [5]. Courtyard performance depends upon its aspect ratio and configuration, degree of exposure, boundary conditions, orientation, and type of surroundings [6]. Adopting courtyard from other climatic zones neglecting indigenous cultural, social and climatic properties of the community may lead to extreme thermal distress in buildings [7]. It has been seen the central courtyard creates a negative pressure zone within which improves the natural ventilation performance where accelerated airflow evacuates the heat upward [8].

Proven successful in past, many of the traditional courtyards around the world have undergone modifications. Although traditional residential courtyards begun to diminish by the second half of the 20th century in Cyprus

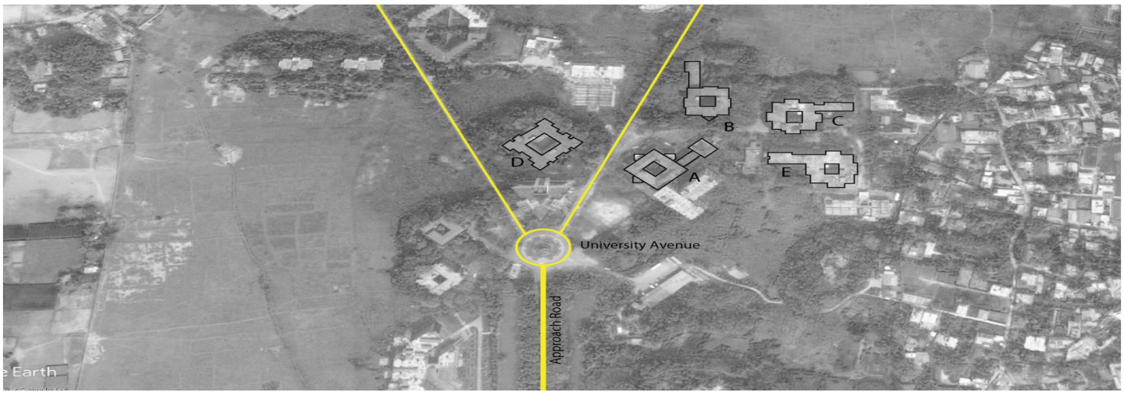

Figure 3. Academic buildings of SUST (Google Earth satellite view, 2020)

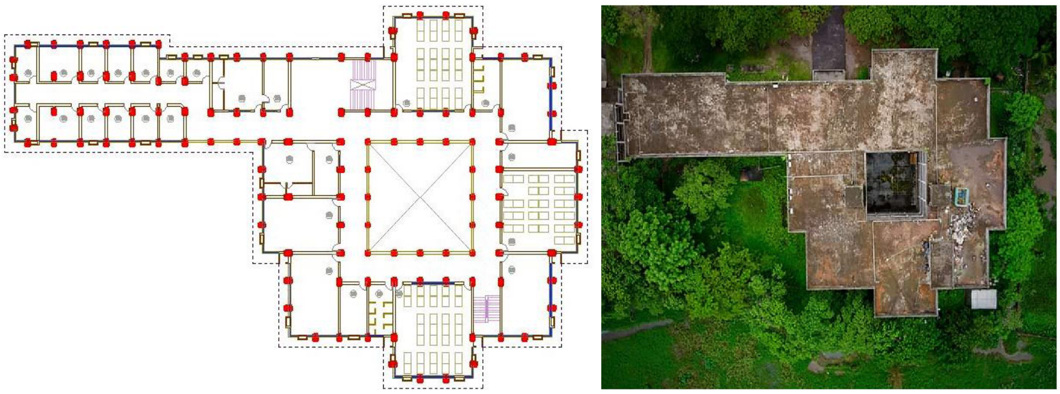

Figure 4. Academic building E: Floor plan and drone view

due to technological advancement, changing lifestyles and socio-economic status, but use of courtyards in educational buildings begun to rise at a remarkable rate for its multidimensional perspectives [9]. In Hong Kong University campus healing properties has been promoted on building courtyards where gardens promoted social support inside a courtyard while the meditation garden acted positive for the academic ambience and helped to construct a good sense of privacy and control [10]. Extreme weather or functional need can create diverse ideas as design of greenhouses in the interior courtyards where presence of water and targeted plant species could create a comfortable microclimate and add significant value [11]. Built form around a courtyard is very familiar in Bangladesh, from rural to urban and vernacular to contemporary architectural works, found almost every region of the country. Ancient educational institutes such as 'Shalvan Vihara' and 'Somapura Mahavihara' remaining till bear the traces of inner courtyards. Many educational and institutional building has been designed with inner courtyard mainly for climatic and social advantages. Courtyards in public buildings such as hospital, government offices, college and universities often leftover due to poor maintenance, sometimes become a place of negligence and waste dumping.

1.3 Academic Learning within Nature

Social and psychological behavior of the students powerfully influenced by campus environment also encourages stress reduction [12]. Students get in touch to natural, significant and influential features of the campus during the field visit and get conscious about the importance of natural surrounding and biodiversity conservation when they engage with campus landscape [13]. As the learning process takes place over entire campus with a continuous flow, fragmented or dedicated indoor rooms are not sufficient to make sure total learning [14]. Stewarding nature helps to build resilience through healthy ecosystem services, competence and social bonding [15]. Installing natural elements inside a courtyard would produce impressive environmental benefits and the thermal comfort [16]. Large number of plants lowers the temperature by evapotranspiration and photosynthesis activities as vapour is released to reduce the temperature of the surrounding [17]. Significant change in academic learning at the university level worldwide engages environmental and social responsibilities to ensure sustainability in local and global context although ecological priorities are still neglected in physical planning phase in most areas [13].

Except few historical conservation or revitalization, study on courtyard reuse or modification is very rare in the field of research. Along with environmental possibilities and socio cultural significance, these courtyards have enormous potentiality to be turned into prospective valuable space for the entire campus. This research aims to explore the potentiality of these courts to connect with the outdoor natural environment to enhance academic learning. At first, the research attempts to identify the present scenario of these courts and related other factors. The next step is to understand the experience and demand of the stakeholders with suggestion from the experts who has experience on designing courtyards in this context. National and international case studies on courtyard design in academic buildings included on the next step and finally a set of acceptable, applicable and manageable recommendations has been proposed. In recent decades a clear paradigm shift has been noticed from a mechanistic to more socio-ecological approach on regenerative design and development around the globe [18]. Composing environmental concerns in aesthetic and emotional terms in the university level has the ability to break down the conventional paradigms to foster sustainability, ecological consciousness, interactive spaces, and speculative dialogue across the disciplines [19].

2. Materials and Methods

In this section, the methods used to obtain the results in the paper should be clearly elucidated. This allows readers to be able to replicate the study in the future. Authors should ensure that any references made to other research or experiments should be clearly cited. A combined approach was adapted to understand the scenario from multidimensional perspectives. Along with the physical survey and literature study research attempted to understand specific experience from the users to identify the factors behind the current scenario and also count the suggestions for future improvement.

2.1 Physical Survey

Physical survey was conducted separately for each academic building to collect information on court enclosure, aspect ratio, building material, surface and vegetation, drainage etc. to construct proper physical overview. The survey also included socio-cultural dimensions to understand the user behavioral pattern and expectation, social and cultural impact on indoor learning environment, recreational use etc. Computer aided model with proper geo location for each building were created for climatic analysis. Both physical and computer based data were compared for different time periods and seasons (Figure 6). Satellite images (Figure 2 and Figure 3) along with photographs (Figure 5) and drone view (Figure 4) have been used to clarify the actual scenario.

2.2 Questionnaire Survey

A survey was conducted among the students of Shahjalal University of Technology, Sylhet from January to March in 2020 asking their opinion toward usage of the inner courts in their academic buildings. The survey included 50 students chosen randomly from each of the five academic building. The questionnaire included a set of ten questions (Appendix A.2.). Eight of those were focused on the necessity of the courts, consistency of use and view towards rethink whether last two was an invitation to broader opinion. Collected data later converted to Likeart scale format (Appendix table A.1.) and create an unambiguous scale to use in satisfaction analysis [20]. The sample size was determined by the following formula: $n = N/1 + N(e)^2$, where 'n' is the sample size, 'N' is population and 'e' is the level of precision which is ±20%. The other two questions covered the ideas, needs and suggestions regarding building specific courts.

2.3 Expert Interview

Opinion from expert bodies helps positive decision making. In this case experts were chosen based on their experience, locality, professional affiliation and academic knowledge. The study team selected two persons as experts from relevant study field, were interviewed about the design intension, present condition, shortcomings, possibilities, affordable and sustainable suggestions on rethinking the existing courts in the academic buildings of the campus considering the surrounding natural advantages. It is to be mentioned that the both selected persons are active faculty member of the University, has more than 12 years of experience in academy and nearly 20 years in architecture profession.

2.4 Case Study

Academic open to sky courtyards were the primary consideration as case studies. Significant features, design intention, appearance, aesthetical appeal, users perception marked as other criteria. Later, cases narrowed down to climatic similarities, relevant building height and mass, aspect ratio and aperture and sensible design for more intensive study. The selection ended up with one national and one international project. For national selection climatic and socio cultural context were also considered. In case of international, sustainable and innovative solutions were considered. First one is the Faculty of Animal Husbandry designed by American architect Paul Rudolph in Mymensingh city of Bangladesh and the second one is the University Presidency building in University of Brasilia, designed by brazilian architect Paulo de Melo Zimbres and Érico Weidle which was built with attractive gardens in a welcoming way visualized as an oasis.

3. Results and Discussion

Academic Building A has the only soil covered courtyard in the campus where other four has plastered ground. None of the courtyards has any define activity. All of the courtyards discourage physical accessibility due to solid brick railing on corridor side. Academic Building D has the largest courtyard and has notable seasonal activities as cultural program, exhibition, mini concerts, indoor sports etc. (Figure 5). Rainwater runoff system works quite well in almost all the courtyards. As seen in Table 1 only academic building 'A' courtyard has some vegetation but not in any clear planned way. The aspect ratio is square but the size of the courtyards mainly contributes to the diverse functional entity. A clear lack of ownership was observed during the survey. Often different departments dump their debris on the courtyard and remain there for a long period of time. The physical barrier was one of the primary deterrents behind the lack of connectivity to the courtyard. From the questioner survey among the participants 210 questionnaires returned maintaining 84% of response rate. The result of students' response regarding the courtyard usage survey is showed in Table 2.

According to Table 2, majority of the respondents agreed on the necessity of a courtyard in their academic buildings. 43% of the respondents feel the extreme necessity of courtyards, 31% of them felt courtyards are very necessary. Despite the fact only 21% of the respondents thought that the use of courtyard is fairly moderate and a majority of 53% of them responded the present usage of courtyard as 'poor'. In the following question they were asked about the idea of modification to connect outdoor nature, 57% of them responded 'very

Figure 5. Present condition of the courtyards of Academic building A, B, C, D and E

Table 1. Overview on comparative physical analysis of different courtyards

Subject	Academic buildings				
	A	B	C	D	E
Aspect Ratio	Square	Square	Square	Square	Square
Dimension(Sq.ft.)	46X46	42X42	44X44	66X66	40X40
Enclosure Material	Exposed Red Brick Wall, Painted Concrete columns				
Ground Material	Soil	Concrete	Concrete	Concrete	Concrete
Permeable Surface	100%	0%	0%	0%	0%
Vegetation	Wild grass, Medium height plantation around edge, One Large Plant around the center	No Vegetation, Algae grow during Rainy season	No Vegetation, Algae grow during Rainy season	No Vegetation, Algae grow during Rainy season	No Vegetation, Algae grow during Rainy season
Drainage	Disconnected Inlet	Disconnected Inlet	Connected Inlet	Connected Inlet	Connected Inlet

Table 2. The result of student response on courtyard survey using Likert scale

Topic of the question	-2	-1	0	1	2
Necessity of court	9%	5%	12%	31%	43%
Usage of court	15%	53%	21%	7%	4%
Modification of court	2%	9%	28%	57%	4%

likely' about repurpose, 28% of them thought the idea was 'likely', 2% of the respondents thought the idea as 'waste of resource'. Then the students respond over six functional ideas, and they choose according to their needs specified to the courtyard they occupy. Shadow analysis help to determine the courtyards exposure to direct sunlight, which influence the use frequency, placement of any function, vegetation and so on. 3ds max geo-location was used to locate the models in their exact locations shown in Figure 6. Three different daytime data of 16th of May & 1st December was generated for each courtyard to overview the major difference between summer and winter. According to this analysis during winter the whole daytime can be utilised for any kind of use as there is no direct sunlight to ground, but there are direct sunlight on the surrounding walls. On contrast in summer exposure is greater resulting in direct use to a smaller extent. Figure 7 demonstrates the count of response on several functions for different courtyards. Here some basic functions like waiting zone, food zone, and cultural activity zone were much anticipated by the responders. Then occasional sports and large cultural activities were popular in the larger size courtyards. Outdoor classroom as a co-curricular function varied with the activity type of different departments occupying different building courtyard.

Experts had expressed their thoughts on multidimensional perspective of actual scenario. Mohammad Shamsul Arefin, Assistant Professor and landscape specialist stated that landscape modification with nature can easily make these courtyards more active and valuable even those are different in size. Innovative and separate modification ideas for each courtyard with different seasonal appearance will break the chain of monotony that can create a unique identity for each academic building. Different ideas may include diverse plantation, seating zone, game zone, amphitheatre etc. but should not include any water bodies as those are hard to maintain and may lead to increasing mosquitoes in campus. Hanging creepers, shaded trees or multilevel plantations on different floors can provide a volumetric green escape zone for the users. He also added plastered ground and surrounded solid railing

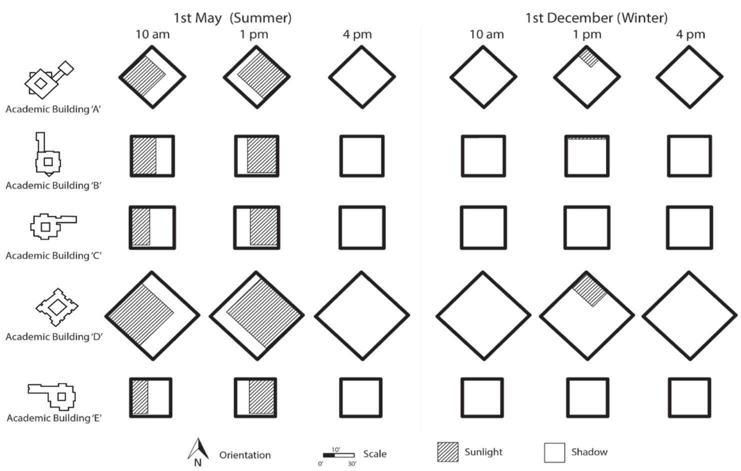

Figure 6. Shadow Analysis of Courtyard Illustrated

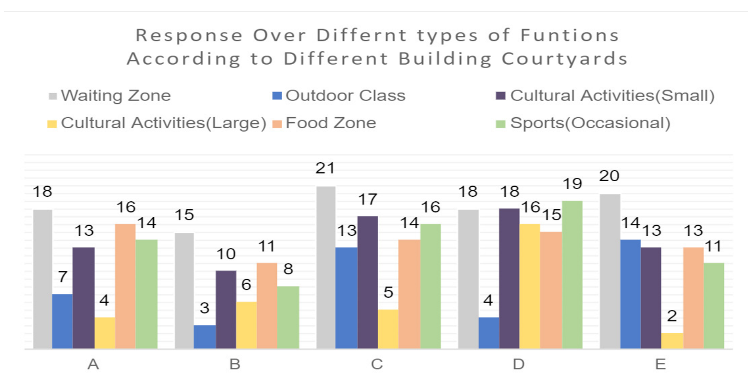

Figure 7. Response on different types of reuse proposal according to different building courtyards

should be removed with more transparent solution to encourage accessibility where ground may include stone chips, grass and attractive landscape furniture with proper drainage installed to deal with heavy rain. The campus is already rich in biodiversity, courtyards with seasonal flowers, fruits and leaves will attract various species of birds and insects that will offer natural stability and healthy learning environment. Kawshik Saha, Associate professor in the same Department, emphasised the universal acceptance of courtyard through its long and successful journey from vernacular to contemporary practice. During his stay in Andalusia he noticed the successive role of courtyard against harsh weather. Enclosed courtyards are common in the contemporary public buildings in the country due to compact structural design, climatic consideration as a source of ventilation and light along with aesthetic purpose as garden and cultural priorities in some cases. He argued that, socio-cultural significance was not considered on designing the courtyards in SUST. Poor accessibility and unnecessary plastered ground made those spaces dumb and trapped. He thinks, student behaviour pattern should be analysed for sustainable modification and outdoor natural environment and biodiversity must be counted on any kind of modification. As student occasionally use some of those courts as badminton court, mini concert, religious ritual as 'Swaraswati puja' and 'Ifter party' and fresher reception program, it clearly indicate the rich cultural environment present in the campus where courtyards might play a major role to construct the cultural backbone of future generation. Vertical landscape and plantation works, seating facilities, provision for outdoor classes, amphitheatre, gallery or multipurpose use character whatever the solution must come through user preference and participation for prime success. Alternation should be minimum, limited to the maintenance capacity, he also added.

Designed by Architect Paul Rudolph, Bangladesh Agricultural University has several prototype courtyards for different faculty connected through shaded corridors. Unique ambience, accessibility and connectivity made the learning environment admirable. The ground level is inviting and accessible with different potted floral plantation over different season is a significant feature here. Architect Paulo Zimbres showed significant natural and structural mingle on his courtyard design in University of Brasilia, Brazil where semi shaded frame used with creeper like vegetation created a pleasant learning and recreational atmosphere (Figure 8).

Figure 8. Faculty of Animal Husbandry, Bangladesh Agricultural University and University Presidency building, University of Brasilia, Brazil

Source: Author and Internet

It is clear that the green natural environment campus of present days is very different from the state when SUST start the journey as a university proposed on a barren paddy land with some treeless hillocks. When the introvert courts were proposed the outdoor environment does not contained any significant natural features. But with the time the campus landscape, scope of work, vision of the authority, user's perception and also the campus planning criteria changed a lot. Peoples concern for natural campus and learning environment added more dimensions on the demands of the users. As seen on the physical survey analysis the courts have many potentialities to integrate the natural environment inside the built form. The users demand also aligned in the same way. Climatic analysis also shows that the courts are quite comfortable to modify with natural features to foster the public gathering and different activities. Expert's opinion, national and international case studies indicates that it is the prime time to invite outdoor nature inside those less active introvert courts with sensible modification proposal. The study concludes with the following recommendations:

- An integrated approach through the participation of the authority, users and field experts could provide the specific guideline to meet the expected result under the capacity of management.

- Impermeable ground surface should be replaced with soil and semi paved solution.

- Solid boundary wall around the court should be removed for better accessibility. Ground level can be left without formal functions to encourage social gathering and informal learning. Small pocket space or balcony on different level will connect the users with outdoor nature.

- Tree selection and plantation should be planned under expert opinion and observation. Multilevel plantation could add a new dimension and foster biodiversity. Vertical creepers on the west side of the court will provide shade on adjacent circulation corridor.

- Modifications of each building court should be considered separately considering the visions, surroundings, user demands, existing uses and scope of maintenance. Creating new identity for each would be more inviting and will help to grow sense of ownership among the users.

- The seasonal variations and different types of positive social gathering should be considered in modification proposal. The desired change should inspire the users, create surprise for the visitor and encourage others to follow.

There are a number of limitations in this work. Larger response from questioner survey could generate more accuracy which was not possible due to time restriction. Scientific measuring and intensive analysis were not possible due to lack of fund and manpower. Design and performance of academic courtyards are common research topic but reusing or modification of public space is still a new topic. So, lack of previous studies in the chosen research area was a negative influencing factor.

4. Conclusions

This research is a primary attempt to stand for the modification of the less used common spaces with natural features to make those leftover assets more live and joyful to the users. This study can easily contribute on creating new resources with less attempt and money even with economic regeneration. In case of Bangladesh, considering this modification issue on the larger public building courtyards can add a significant change on the people's perception of built environment.

Acknowledgments

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Appendix

Table A.1. Likeart scale value used in Courtyard survey:

Topic of the question	-2	-1	0	1	2
Necessity of court	Not at all	Slightly	Moderate	Very	Extremely
Usage of court	Very poor	Poor	Fair	Good	Very good
Modification of court	Waste of Resource	Not Likely	Likely	Very Likely	Burning Need

A.2. Questions used in survey:

1. Which academic building you belong to?

i)A ii)B iii)C iv)D v)E

2. How important do you think the presence of courtyards in the academic buildings in the campus is?

i)Unnecessary ii)Roughly necessary iii)Necessary iv) Very necessary

3. How are the courtyards of the academic buildings of the university being used?

i)Going unused ii)Being used sparingly iii)Being used properly

4. What is the scope of versatility of the courtyards of the academic buildings of the university?

i)There is no chance ii)There is a fair chance iii)There are opportunities

5. Which academic building are you currently directly involved with?

i)A ii)B iii)C iv)D v)E

6. What kind of courtyard activities in your academic building can ensure its proper use in the future?

i)Sports ii)Cultural iii)Occasional iv)Waiting zone v) Co-curricular vi)Others

7. Which academic building courtyard do you like the most?

i)A ii)B iii)C iv)D v)E

8. Which courtyard of an academic building do you feel is not being used properly?

i)A ii)B iii)C iv)D v)E

9. What other courtyard do you see that is being used better than your campus?

10. Any other comments on the courtyard of the academic building on campus?

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EDITORIAL

Towards Sustainable Living: From COP21 to COP26 and Beyond

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The publication of the Brundtland report in 1987 set the new agenda for world business when it presented the universally recognized definition of sustainable development that fulfills the present demands without compromising the ability of future generations to meet their own needs [1]. Since then, sustainability has been much debated at all forums, and various studies show that we are overstressing our mother planet by stretching the limits of our lifestyle. If the lifestyle does not change, the planet's life will be at the most significant disaster risk. The publication of the Brundtland report brought the word sustainability into the political arena at the world level that, is considered a core pillar in economic development. Every year United Nations host a Climate Change Conference or simply COP. In every COP, the world leaders present the recent progress and the future pledges to meet the UN agenda on sustainability. The COP21 held in Paris 2015 was one of the remarkable events that had set many KPI for progressing towards sustainable living. The main focus in COP21 was given to two primary issues: temperature rise and funding resources to developing and under-developed nations. The critical temperature limit was recommended to set at 1.5 °C or 2 °C above preindustrial levels. It was also urged that the developed nations award appropriate funding to developing countries potentially vulnerable to sea-level rise and expectedly more severe weather events [2]. The pledge made for zero net greenhouse gas emissions was targeted during the second half of the 21st century. However, it was reiterated that if the temperature increase is required to be limited to 1.5 °C, zero net emission aspiration should be achieved from 2030 to 2050 [2]. Towards the end of 2021, there were two beliefs about the climate action and the progress on COP21:

• The Paris Agreement is working as it was aspired, doing what it is supposed to do and what it can do as an

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international agreement.

• The Paris Agreement agreement alone cannot save us. The global response to climate change is not generating transformation at the pace or scale we need to avoid the worst impacts of climate change.

In December 2021, Glasgow was the moment for countries to update their plans to reduce emissions. Unfortunately, the summit was delayed by a year due to the COVID-19 outbreak. It was obtained that the commitments laid out in Paris did not come close to limiting global warming to 1.5 degrees, and the window for achieving this is closing. The most significant takeaway of the COP26 is that the direction of travel is clear when it comes to climate change: achieving net zero emissions by 2050 or sooner. However, the speed, mode, and path of travel are less noticeable.

The five most significant takeaways from COP26 are: for the first time; country commitments brought the world closer to the goal of limiting global warming to well below 2 °C. In addition, methane took center stage, with more than 100 countries signing on to the Global Methane Pledge. Methane is one of the most potent greenhouse gases, and the pledge is to cut methane emissions by 30% by 2030. A broader-than-expected coalition signed on to a commitment to halt global deforestation. References to coal and fossil fuel subsidies made their way into a new Glasgow Climate Pact. The rulebook for voluntary carbon markets was finally established [3]. Let us hope for the best to fulfill the commitments and pledges made to make our mother planet livable for today and tomorrow.

In modern society, most people spend 90% of their time in the built environment [4]. Therefore, people will have higher and higher requirements for the built environment. In addition to sustainable energy conservation and emission reduction, the livability of buildings is also more and more attention. The continuous update of green building materials has brought a better orientation to the building environment. Architects, engineers and construction personnel work together to ensure the quality of the built environment.

Journal of Architectural Environment & Structural Engineering Research, a peerreview and open access journal, provides a good service platform to publish these related study results. Certainly, all topics related to the built environment, structural engineering could be accepted to publish on this journal.

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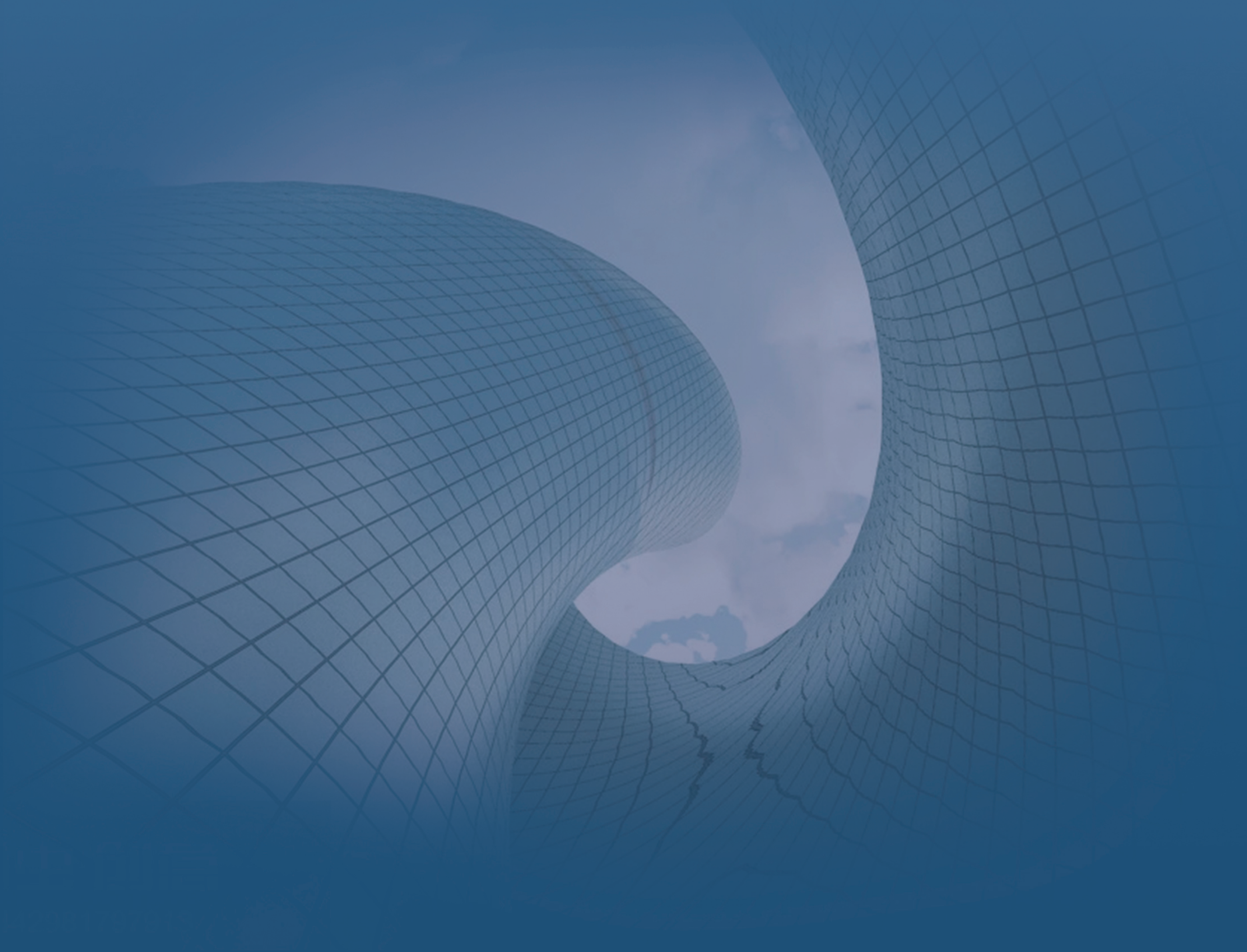

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