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- His Majesty The King

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Introduction

Gross National Happiness(GNH) Journal of Construction Technology and Management is now publishing its second edition. It is gaining popularity amongst the authors, technical experts, academicians, policy makers and we encourage introducing new ideas and concepts in the Bhutanese construction industry.

The GNH Journal of Construction Technology and Management is not just focused to the key players of the construction industry and procuring agencies of the nation but to create a community of people who will contribute to the nation building. The Journal is focused to encourage any individuals to engage in technical research that can be available to publics.

The GNH Journal of Construction Technology and Management is a non-biased publication. Our purpose is to serve the national interest through dissemination of information, and discuss issues related to the construction industry from every constructive point of view. We hope that the objectives are the best way to serve our country and His Majesty The King.

We invite the participation of all interested individuals of Bhutan in this endeavour.

Contents

Viability of Concrete Pavement in Bhutan: A Review

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Abstract: The coverage, standard and state of the road infrastructure of a country has a direct and significant bearing on the health of its economy. The choice of materials to be used for the various components in a road pavement is among the various crucial aspects of planning and design for a safe, comfortable and durable road network system. Road pavement surfaces are typically of two kinds, the all too familiar bitumen (asphalt) based surface known as the flexible pavement and the cement concrete-based surface known as rigid pavement. The review focused on the structural, functional and cost attributes of two pavements including highlights on climatic conditions and environmental impact in terms of carbon footprint. This review has shown that rigid pavement roads are economical and environmentally friendly than flexible pavement over the course of the road's design life and more so when the roads are to be built over very weak underlying soil (subgrade) conditions under higher traffic loads.

Keywords: Viability, concrete pavement, economic benefit, LCCA

Introduction

Rigid pavement road concept and construction is a recent phenomenon in Bhutan. Apart from the few isolated cases of trial stretches of few kilometers being built at Yotongla on the East-West national highway and at Nanglam, the viability and the potential of the technology is yet to be explored and tapped in an earnest and concerted manner in Bhutan. Recent improvements in the design, construction and maintenance techniques have led to the rigid pavement being just as economical and under some conditions even more economical than flexible pavement. The use of rigid pavement in our road construction seems to bear multiple positive impacts in Bhutan. Our country, at present, is presented with the best circumstantial opportunity from both the demand and supply side of the equation to explore the viability of the rigid pavement as a potential option in the construction, maintenance and up-gradation of our roads. On the demand front, with only 30 % of the total road length of approximately 12,000 km with paved/sealed surfaces (NTP, 2017) there is almost around 8400 km of the road still to be provided with the pavement surface layer at present. A standard rigid pavement construction for this work would require around 41.58 million tons of cement. The amount of surfacing work required is only bound to rise by manifolds considering the volume of new road works envisaged in the country's Transport 2040 integrated strategic vision document. On the supply side, a key ingredient in rigid pavement construction is

cement. There are several well-established states of the art high-capacity cement producing plants in the country. Considering that Dungsam Cement Corporation Limited (DCCL), one such industry alone has a production capacity of 1.36 million tons of cement per annum presents a very promising and exciting prospect. The construction of flexible pavement requires the use of bitumen as a primary material. Just in the year 2017, our country has imported 5617.706 tons of bitumen and bituminous based material worth around Nu. 62.9 million (BTS, 2017). Given all the seeming benefits and the opportune timing, Druk Holding and Investment (DHI) in partnership with the College of Science and Technology (CST) and Department of Roads (DOR) has collaborated to undertake a joint project to assess and prepare a report on the viability of the rigid pavement for the roads in our country under various feasibility conditions.

The Road Pavement

Flexible and rigid pavements are typically laid for roads and are most common (Figure 1). A flexible pavement comprises properly heated, mixed and compacted layers of bitumen and a mixture of aggregates laid on a bed of granular layer resting on the prepared natural soil base known as the "subgrade". In the country, rigid pavement is composed of cement concrete or reinforced concrete slab which is laid on dry lean concrete (DLC) base or soil subgrade that is well compacted as per the specification. In some cases, both layers are required when the strength of the sub-base is very low. Sub-base, base course and bituminous surface layer form the overall thickness of the pavement.

(**a**) (**b**)

Figure 1. Types of road pavement (**a**) Flexible pavement-asphalt concrete; (**b**) Rigid pavement-cement concrete (Picture courtesy: www.nbmcw.com)

Usually, top surface layers are composed of one or more layers called Dense Bituminous Macadam (DBM) and Asphalt Concrete (AC) (Figure 1a). This pavement type is flexible to undergo deformation under traffic load as it possesses negligible flexure strength. The combined

additive forces of internal grains in the granular materials substantiate the overall structural capacity of this pavement.

The traffic loads get disseminated (e.g., like truncated cone) through the layers of the base, sub-base, subgrade courses, and then ultimately to the ground. Since the stress induced by traffic loading is highest at the top, the top surface layer should be of the highest quality. The subgrade layer is responsible for transferring the load from the above layers to the ground. The thickness of the flexible pavements' layers is designed in such a way that the load that reaches the subgrade does not exceed the bearing capacity of the subgrade soil. Based on the strength of the sub-surface soil and the traffic load in consideration, the thickness of the pavement is estimated.

The key difference between the two pavements is presented in Table 1. Rigid pavements (Figure 1b) are so named because of the high flexural rigidity of the concrete slab. The pavement structure deflects very little under traffic loads due to the high modulus of elasticity of the concrete slab. The concrete slab acts like a rigid plate/slab resting on a flexible base.

Table 1. The key differences between the two pavements (Courtesy: www.theconstructor.org)

Features	**Rigid Pavement**	**Flexible pavement**
Composition	Consist of one layer of cement concrete slab (usually OPC)	Consist of series of layers of bitumen aggregate mix and granular material with the highest quality material at the surface
Surface Deformation	Rigid and able to bridge over localized failure and areas of inadequate support	Flexible and reflects the deformation of the subgrade and subsequent layers and deformation
Source of Strength	Strength provided by the slab through beam action	The strength provided by aggregate interlock and particle friction and cohesion
Key Design Parameter	Flexural strength of concrete The fatigue life of concrete Modulus of subgrade reaction	Soil subgrade strength CBR value of subgrade
Effect of Temperature	Temperature variation induces high stresses	No additional stress induced
Service Life	30 - 40 years	10 - 15 years

In rigid pavement, the depth of the bearing slab and the number of the pavement layers can be minimized or optimized because of its high flexural strength which is capable of distributing traffic loads to a large area. At joints, dowel and tie bars are mostly employed. A smooth reinforcing bar that runs in a transverse direction is called dowel bar which functions as a mechanical connection and transfers the load between the slab. This provision restricts the horizontal

movement of the slab panels. On the other hand, tie bars which are normally deformed steel bars are used in the longitudinal direction and hold the faces of abutting slabs that are in contact. With the minimal load transfer that happens through the tie bars, they are not designed to act as load transfer devices and are simply used to 'tie' the two concrete slabs together.

The Review

Sound and Noise

Traffic noise pollution has become a growing problem that affects human psychology and the living environment (Li et al., 2016). Tires of a heavy vehicle that have distinct blocks and gaps which is usually called the tread pattern exhibit louder noises compared to small passenger cars (Ramussen et al., 2007). Tire-pavement noise, which is a dominant contributor of overall noise emitted as a result of the interaction of tires and the pavement surface (Sirin, 2016). Porous asphalt concrete of one or more layers pavements has been shown to improve the noise reduction capability (Meiarashi and Ishida, 1996; Sandberg, 1999; Nelson et al., 2008). According to Donavan and Rymer (2003) such porosity provides a 5 to 10 dB reduction in tire or pavement noise over conventional surfaces of various types. Also, the noise level can be reduced to 2 to 3 dBA by the addition of rubber (Tehrani, 2015). Primarily, the noise level is highly dependent on porosity, thickness, gradation and texture of the pavement surface (Abo-qudais, 2004; Hanson et al., 2004; (Parnell and Samuels, 2006; Cackler et al., 2006; Rasmussen and Sohaney, 2012; Rochat and Read, 2013). We conclude from this review that concrete pavement produces more noise than asphalt pavements. For highways with noise issues, diamond ground surfaces are the solution of choice for producing quiet concrete pavements with less expense (Bennert et al., 2005).

Business and Cost Parameter

We present the economic viability of the rigid pavement in comparison to flexible pavement in this section. The cost of the pavement grossly depends on soil condition or strength of the subgrade expressed in terms of California Bearing Ratio (CBR), traffic load and fuel cost among others. The study indicates that no significant variation in the thickness of the rigid pavement with increase in the value of CBR, while the cost of flexible pavement decreased with increase in the value of CBR but the cost of flexible pavement increases with an increase in traffic (Jain et al., 2013; Naik and Sachdeva, 2017). Construction cost for flexible pavements is cheaper than rigid pavements; however, with the strength increase in subgrade the asphalt pavement costs and rigid pavement costs get closer and with the increase in the fuel prices, the cost of asphalt pavements will be even higher (Akakin et al., 2013). The fuel cost saving for a passenger car on the concrete pavement is 3.2% less than on flexible pavement (Bienvenu and Jiao, 2013).

The findings from a study (Chandra, 2017) on cost comparison conducted in India on a 1.0 km stretch of some 90 pavements for a two-lane road with 7.0 m carriageway and 1.5 m wide shoulders on either side on varying values of soil subgrade CBR and design traffic load is discussed here. The soil subgrade CBR ranges from 2 % to 10 % and the design traffic range from 1 msa to 150 msa was considered in the study. The points of equal cost on the CBR vs msa graph is plotted (Figure 2) to infer the condition for equal cost for the two pavements. In the upper portion of the plot, the rigid pavements are inclined more towards the economic zone against the flexible pavements at the lower portion of the graph.

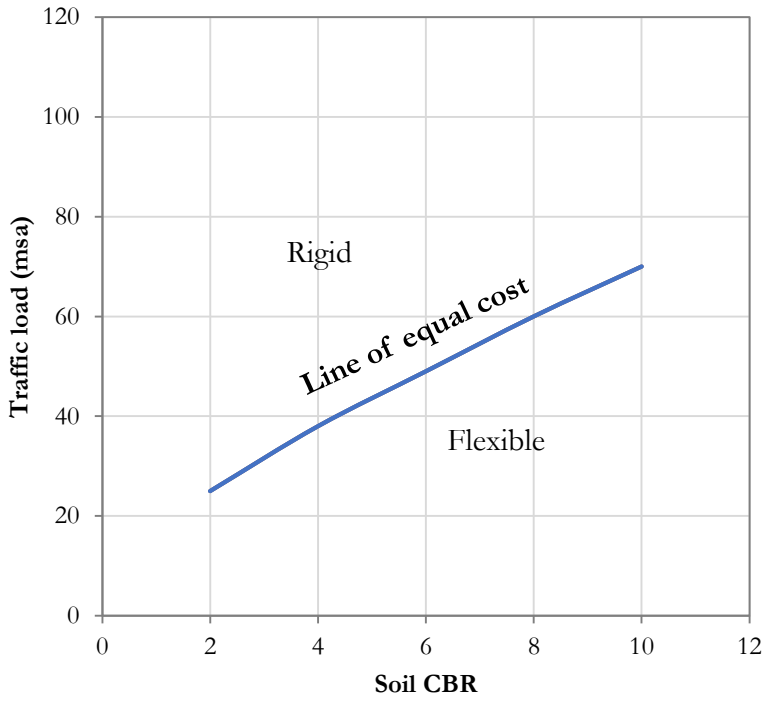

Figure 2. Line of equal cost for flexible and rigid pavements (Chandra, 2017)

Rigid pavement is more economical for areas with lower soil strength and higher traffic load; and the flexible pavement in areas with better soil condition and lower traffic volumes. Most studies reveal similar observations. There is a need for a proper comparative study based on relevant design parameters to determine the better choice. The following equations capture the impact on the cost of varying CBR and traffic values.

$$Cost = -16.98 + (12.136 x CBR^{-0.3}) + (15.476 x msa^{0.10)} \quad (1)$$

$$Cost = 8.284 + (4.719 x CBR^{0.9}) + (20.83 x msa^{0.15}) \quad (2)$$

For (msa < 12.48 + 6.05 x CBR); the flexible pavements are more economical

For (msa > 12.48 + 6.05 x CBR); the rigid pavements are more economical

For (msa = 12.48 + 6.05 x CBR); Both the pavements have equivalent cost

The initial cost of rigid pavement is usually more than twice the flexible pavement, however, due to lesser repair maintenance cost, a cost of $105,526.13 USD per kilometer will be saved for an analysis period of 40 years (Ketema et al., 2016) with economical finding during the service life of a rigid pavement by (Khurshid et al., 2008; Jain et al., 2013; Taher et al., 2020) and reported economically sustainable (Moretti et al., 2012). Life Cycle Cost Analysis (LCCA) also show economical benefit of a rigid pavement (Crarnecki et al., 2017; Babashamsi et al., 2016) with some finding up to 38 % (Hamim et al., 2020) to 55 % (Ashok and Ashwini, 2017). Also, LCCA shows concrete pavement most sustainable and preferable alternatives in terms of reducing negative environmental impact, economic and social impact as well (CCAA, 2010; Choi et al., 2016). In Bangladesh, it is found evident that 1km of flexible pavement costs 3 times to 1 km rigid pavement in 20-year Life Cycle (Ur, 2015). A study conducted by (Abbasianjahromi et al., 2020) mentions that the economic risk is lower for concrete pavement due to the high probability of change in fuel price.

Impact, Smoothness and Comfort

The impact of vehicles on rigid pavement mainly focuses on the performance and lifespan of rigid pavements. The performance can be affected by farm equipment (S. Wang et al., 2012), dynamic loading (Stoner et al., 1990; Izquierdo et al., 1997), and variation in velocity (Darestani et al., 2006). Dynamic wheel loading can cause more stress in corners. The highest stress occurs on the transverse and longitudinal edges of the slab using the design axle and an axle with the maximum allowed weight. The most unfavorable effect caused by stress in the middle of the slab was from the non-standard axle with stress achieving a value of 23.32 % higher than the stresses from the design axle (Bartosova, 2002). Precaution needs to be taken to design the corner section to achieve zero pavement maintenance. Sub-base erosion phenomenon is more pronounced relating to deflection and subsequent distress in the concrete pavement under dynamic loadings (Stoner et al., 1990); and modeling of dynamic vehicle loads is recommended (Stoner et al., 1990; Gillespie et al., 1992).

The standard tool for evaluating the pavement roughness is scaled with reference to International Roughness Index (IRI) which defines ride comfort and IRI (Cackler et al., 2006; Izevbekhai et al., 2007; Chen et al., 2020). In some studies, a threshold value of 4.50 m/km was indicative to achieve smoothness of the pavement (Chen et al., 2020). According to (F. Wang and Easa, 2016), ride comfort is primarily related to a weighted root mean square of acceleration (a_w), the weighted value of subjective comfort (C_w), root mean square of successive heartbeat interval

differences (RMSSD) which is accounted as a function of IRI. The experimental and analytical methods indicate comfort ride in light passenger cars up to IRI 4.0 mm/m. (Holloway, 1956) recommends the following roughness index based on the research carried out for Indiana concrete pavement for new high type pavement construction as shown in Table 2.

Often some indices such as Ride Number, Michigan Ride Quality Index (RQI), Minnesota Ride Quality Index and frequency-weighted vertical acceleration, a_{wz}, according to ISO 2631 are frequently used to evaluate ride quality level sensed by the users (Loprencipe and Zoccali, 2017). In general, flexible pavement provides a smooth riding surface than concrete, however, slip-form paving yielded improved smoothness of the concrete pavement (Rizenbergs et al., 1973). We reviewed that while designing a rigid pavement emphasis should be given on dynamic loading, the roughness of the surface, stress distribution especially in the corner section and the type of vehicles.

Table 2. Roughness Index for corresponding riding qualities

Roughness Index (in per mile)	Riding Qualities
Below 75	Good (Acceptable)
75 to 90	Fair (Acceptable)
Above 90	Poor (Not Acceptable)

Quality, best practices in similar climatic conditions and orography

Joints in Jointed Plain Concrete Pavements (JPCP) are the weaker zones that crack during summer due to temperature variation. An improvement option is to make saw-cuts deeper with Relative Joint Depth (RJD) of 45 % for Effective Slab Length (ESL) of 4 m except for temperature variation of 2°C with stronger coarse aggregates (Pradena and Houben, 2016). Mammeri et al. (2015) highlighted that there is a significant impact of different thermal parameters like heat transfer coefficient and thermal conductivity of layers, and daily temperature variation causing thermal cracking of the pavement. Also, studies show temperature effects are largely notable to effect on pavement performance among other climate change parameters (Gudipudi et al., 2017). The review also indicates that the temperature difference exceeds the failure load defined by $0.4\times\sqrt{f_{cu}}$ as a result of thermal-expensive stresses and overall, the impacts are severe under climate change projections which increases the likelihood of cracking (Chai et al., 2012). Literatures emphasized that concrete pavements are the best pavements with longer service life, except due to its distress, which is manageable. It was also highlighted that distress is due to traffic and thermal

stress. Thus, thermal distress needs to be studied and incorporated in the design along with mechanical stresses which are extensively compared and studied (Tayabji, 2010). Concrete pavement fails over a period of time due to distresses like cracking due to poor design and construction practices, joint faulting due to load transfer at transverse joints, spalling due to poor joint sawing practices and quality of concrete, roughness due to other stresses and during construction, surface texture loss due to high volume and speed applications. However, Tayabji (2010) suggested that the distress developed is manageable by incorporating sound design, durable materials and quality construction practices and the threshold value is recommended as presented in Table 3.

Table 3. Recommended threshold values for concrete pavement distresses

Distress	Threshold value
Cracked slabs, % of total slab	10 to 15
Faulting, mm	6 to 7
Smoothness (IRI), m/km	2.5 to 3.0
Spalling (length, severity)	Minimal
Materials related distress	None

Rigid pavement is also susceptible to damage due to frost penetration depth, and the number of freeze/thaw cycles experienced by the pavement apart from the pavement's surface temperature. The Freezing index is a common metric for determining the freezing severity of the winter season and estimating frost depth for mid-latitude regions, which is useful for determining the depth of shallow foundation construction (Bilotta et al., 2015).

The most critical failure mode in AASHO (1962) test sections was an erosion of sub-base or subgrade materials, whereas, the predominant failure modes in many rigid pavements are faulting and fatigue cracking (Highway Research Board, 1962).

Carbon Footprint

With global challenges of climate change and environmental degradation, the impact on the environment is also a very crucial parameter to judge a technology's viability. Some key measuring yardsticks are the carbon footprint and the embodied energy (Huang et al., 2016). Like any construction materials, road construction consumes energy (embodied energy) in five phases: a) Manufacturing of construction materials, b) Site preparation; c) construction of roads and transportation, d) Maintenance of road and, e) Energy consumed in demolition and recycling.

According to Associated Schools of Construction (2018), when 50-year life-cycle GHG production was compared, concrete pavement and asphalt pavement produced approximately 1610 CO_2e tons/km and 500 CO_2e tons/km respectively indicating that for every 1,000 kg of Portland cement, about 730 kg of CO_2 is produced. According to (Espinoza et al., 2019), after an LCCA study, it was determined that the construction of the hot mix asphalt (HMA) layer generates a carbon footprint of 65.8 kg of CO_2e per km of road. Similar studies and review findings are also indicative of high carbon footprint in the overall life cycle of concrete pavement construction (Häkkinen and Mäkelä, 1996; Santero et al., 2010; Mukherjee and Cass, 2011; Kar et al., 2015; Ma et al., 2016; Zainab Ali Hulail, Afizah Ayob, 2016; Utomo Dwi Hatmoko et al., 2020; Singh et al., 2020).

This section illustrates the comparative study conducted between the two pavements by Chandra (2017) The study was carried out on a pavement of 1 km stretches with a 7.0 m wide carriageway designed for a subgrade CRB value of 8% and a traffic loading of 100 msa with standard pavement specifications. It revealed that 96 % of total greenhouse emission for rigid pavement comes from the embodied energy of the material. A substantial amount of energy is consumed during the construction of flexible pavement. Assuming, equivalency in embodied energy of materials like cement and steel bars and considering primary emission during construction, the lower emission is evident for rigid pavement.

Table 3. Life cycle carbon footprint of pavement per km

Source	**Emission in tons of CO_2 equivalent**	
	Rigid pavement	**Flexible pavement**
Raw material embodied energy	1246.00	95.00
Construction stage	6.60	84.00
Transportation and logistics	46.70	40.70
Maintenance	NA	NA
Demolition/removal	NA	Na
Total	**1299.30**	**219.70**

Considering that the cement is manufactured regardless of whether it is to be used for pavement construction or not in Bhutan, rigid pavement construction will have a lower adverse impact on the environment. However, this is based on data available for the first three phases of the road lifecycle as data on energy consumed for the maintenance and demolition phase were not

available. It is vital to analyze the maintenance impact as rigid pavement will require less maintenance than flexible pavement because of its longer service life.

Conclusion

The design traffic load and the site's subgrade condition govern the choice of a pavement type for any stretch of a road. In cases where the soil subgrade is weak (like clay) and places with heavy precipitation and proper drainage conditions are difficult to maintain, rigid pavement is the better choice. But at sites with good quality soil subgrade and where traffic is also not very heavy, flexible pavements are more economical. Therefore, the assessment of the site CRB value and forecasting of the anticipated traffic volume and load is vital to determine the choice of the two pavements. Considering the CBR value, traffic load and cost, it is indicative that the rigid pavement is more sustainable as compared to the flexible pavement due to durability and capacity to take much heavier loads. Project-specific comparative cost analysis is also very important as prices of materials and equipment and labor are subject to change based on the prevailing economic condition of the region. However, LCCA through the review indicates the sustainability of rigid pavement for up to 40 years provided the right implementation of technology and quality. To the best of the author's knowledge, the topographical and climatic condition of a region still remains a challenge. It is important that geometric designs are aligned to the topographical features of the route.

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Analysis of Delay Factors in Construction Project Using RII Method

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Abstract: Project delay is considered one of the most common problems causing a multitude of negative effects on the project and the parties involved in the construction project. This paper aims to identify the main causes of delay in construction project from the perspective of procurement officials and civil engineers taking the case study of Government Funded Projects within the Dewathang area. The literature review was conducted to assemble the list of delay reasons and measure to minimize the delay. In this study, it captures the interviews of 32 respondents (8 procurement officials, 8 Project Managers, and 16 civil engineers) through a survey questionnaire using Google Form. The MS project software was employed to determine the time duration of the selected projects and subsequently, the data analysis was done using the RII method. From the findings, the top 10 most common factor causing the delay; 5 factors from procurement and civil engineering with the highest ranks have been listed. Also, the highest rank measure to reduce delays such as proper project planning and scheduling; awarding bids to the right contractor; proper site management & supervision; and properly use of modern construction equipment are effective measures suggested to minimize construction delay.

Keywords: Project Delay, Time Overrun, Cost Overrun, Microsoft Project and Relative Importance Index Method

Introduction

The delay in construction projects could be defined as the excess of time beyond the actual time stipulated in the contract parties agreed upon for the accomplishment of the project (Shahsavand et al., 2018). When there is a delay within the dated project time frame, the total cost of the project will be increased for contractor, which might affect project sustainability. Furthermore, the time required to complete the project will be readjusted to be a longer date and hence, will lead to negative impacts on both the project duration and relationship between project parties.

Globally, a considerable amount of construction projects suffer time overrun and the effect of this time overrun may be of greater magnitude on the overall performance of the project. To

minimize the effect and overrun, the reasons for the occurrence should be recognized (Bekr, 2018). In Bhutan the construction sector plays an important role in the national economy as in the 11th five-year plan, 60% of the total budget outlay was allocated for procurement, out of which 80% account for construction work and the sector's contribution is expected to increase in the coming years with accelerated development of hdro-power projects (Nima, 2018).

Therefore, this study aims to identify, rank and discuss the most prominent factors causing delay by using the MS project and Relative Importance Index method. The targeted respondents were project manager, procurement officer and civil engineer since they are the one who involved in all construction project. The analysis of the result was based on the responses provided by respondents from their experience in the past and ongoing project in Bhutan.

Literature Review

Delay in a construction project can be defined as the late completion of work as compared to the planned timeframe or it's the time overrun or extension of period to complete the project and claims that it cannot be avoided (Hedaoo & Hatkar, 2016). Delay in the construction project is considered one of the most common problems causing many negative effects on the project and its active parties (T. Subramani, n.d.). Therefore, the delay is a state when the actual progress of a construction project is imperceptive than the planned schedule or late completion of the projects.

In the constructions industry, delays are due to poor contractor experiences, ineffective project planning and scheduling, poor site management and supervision, change in design were some of the crucial factors causing delay identified from a civil engineering point of view (Sivaprakasam et al., 2017). On the other hand, it is found that improper implementation of the legislative framework, funding, corruption, hostile operating environment, inadequate knowledge of practitioners of procurement methods and unbalanced economic environment are factors affecting construction delay from a procurement point of view (Ogunsanya et al., 2019). There are many factors causing delay and different researchers have identified the factors and the methods that could be adopted. It was also realized that the cost and time overrun were crucial intimidations of project delay. So far, no research has discussed the collaboration base on civil and procurement factors related to project delay.

The study has been made to overcome the problem in the study that encourage to collect the day-to- day data in site work i.e., starting time, finishing time and completed task are recorded in MS Project differentiating task and critical activity along with the delays produced and reasons for the delays (Kumar, 2018). However, there has been no study made on various software with the highest rating to manage project management which includes practical analysis for the same.

Methodology

To conduct the feasibility study, firstly the factors that cause a delay in construction and methods of minimizing delay was listed down through literature reviews. A questionnaire survey was prepared to have twenty-one civil related causes, twenty-four procurement management causes and eight methods of minimizing delay.

Furthermore, the arithmetical method i.e., Relative Importance Index (RII) was used to analyze the data from the questionnaire survey by ranking the factor and finding crucial ones based on participant's replies. The Relative Importance Index (RII) (Enshassi, A., Mohamed, S., Abushaban, S., 2009) is calculated for each factor and ranked accordingly with the mathematical expression given by:

$$RII=\frac{\sum W}{AN}=\frac{5n_5+4n_4+3n_3+2n_2+n_1}{5(n_5+n_4+n_3+n_2+n_1)}$$

Where: W is the weightage of individual factor,

$\sum$W=Summation of all weight of each factor,

A is the highest score; and

N is the total respondents.

In this study, the RII stages are set in between 0 to 1 ($0 \leq RII \leq 1$). The value 1 is the highest importance rating for the cause of delay.

To obtain the principal factors causing construction delay a case study was conducted through an online interview in the form of a questionnaire survey. The average of the methods to minimize delay was calculated to obtain the best four effective methods. To determine project duration and prepare to schedule, software called MS-project was used.

Data collection and Result analysis

The data collection was done from the questionnaire survey, case study and the work breakdown schedule. The quantitative approach was used to understand the perception of project managers, engineers and procurement managers towards factors influencing construction delay. Two sets of questionnaires were prepared using the Likert scale in Google form i.e., civil related and materials and procurement related.

Analysis of questionnaire survey

The data collection was done from the questionnaire survey, case study and the work breakdown schedule. The quantitative approach was used to understand the perception of project

managers, engineers and procurement managers towards factors influencing construction delay. Two sets of questionnaires were prepared using the Likert scale in Google form i.e., civil related and materials and procurement related.

Causes of delay in construction projects

On analyzing the data collected from the targeted respondents using the relative importance index, the following result was achieved whereby the most principal factors with a crucial contribution to causes of delay were determined.

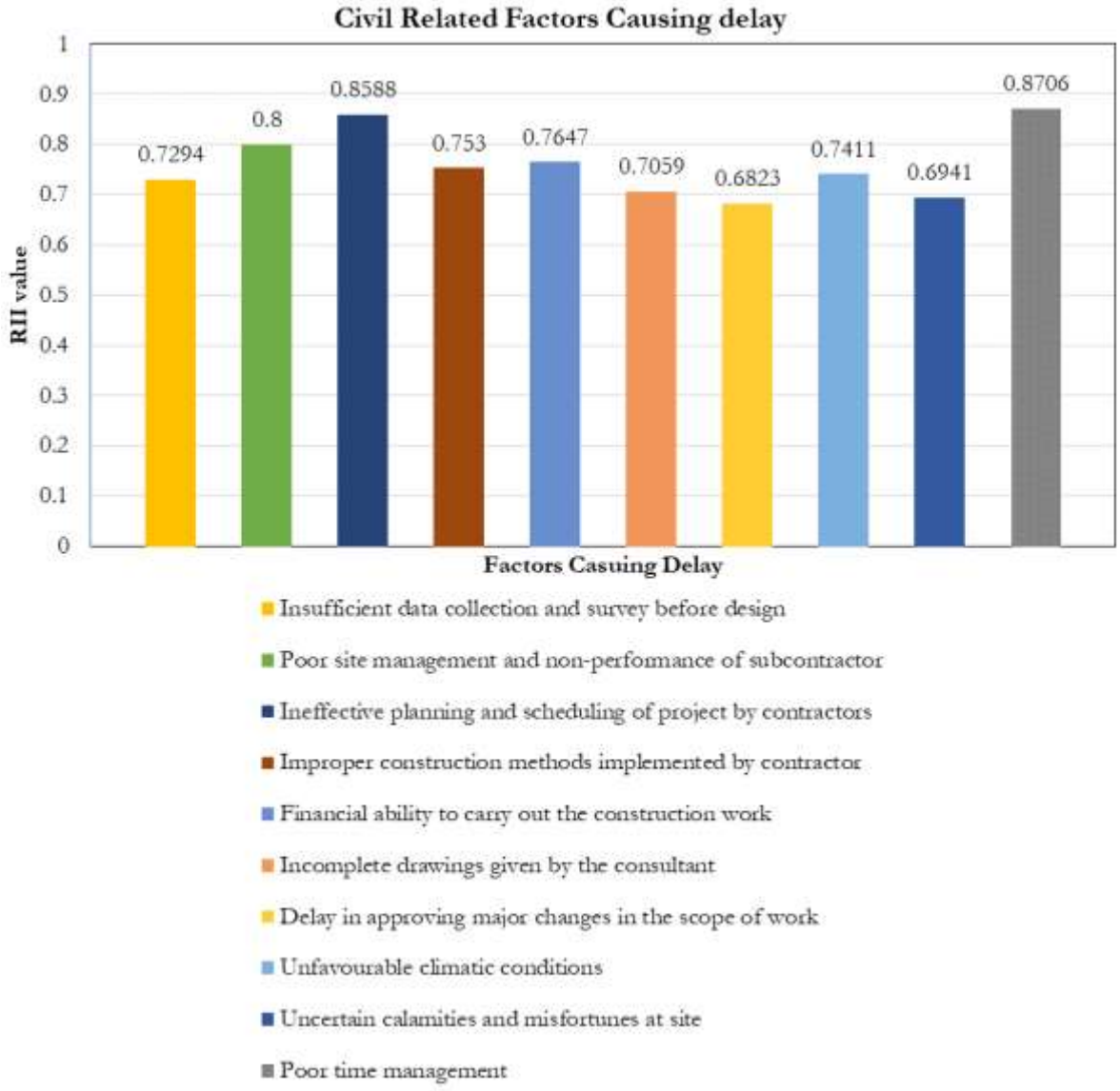

Figure 1. Civil related factors causing a delay in construction

The graph in figure 1. labels the ranking of civil related factors adding to a construction delay. On analyzing the factors by calculating their RII value and on ranking them, it was noted that of twenty-one (21) factors, the top five factors with their crucial contribution to delay are poor

time management, ineffective planning and time framing of projects by contractors, poor site management and non-performance of subcontractors, financial ability to carry out the construction work and improper construction methods practiced by contractors. Figure 1, which exhibits the causes of delay in graphical form also indicated the other than top five factors causing a delay which are; late payment of bills, unbalanced relationships, sub-contractors with employees, conflict among Joint ownership and unavailability of utilities in site (such as water, electricity).

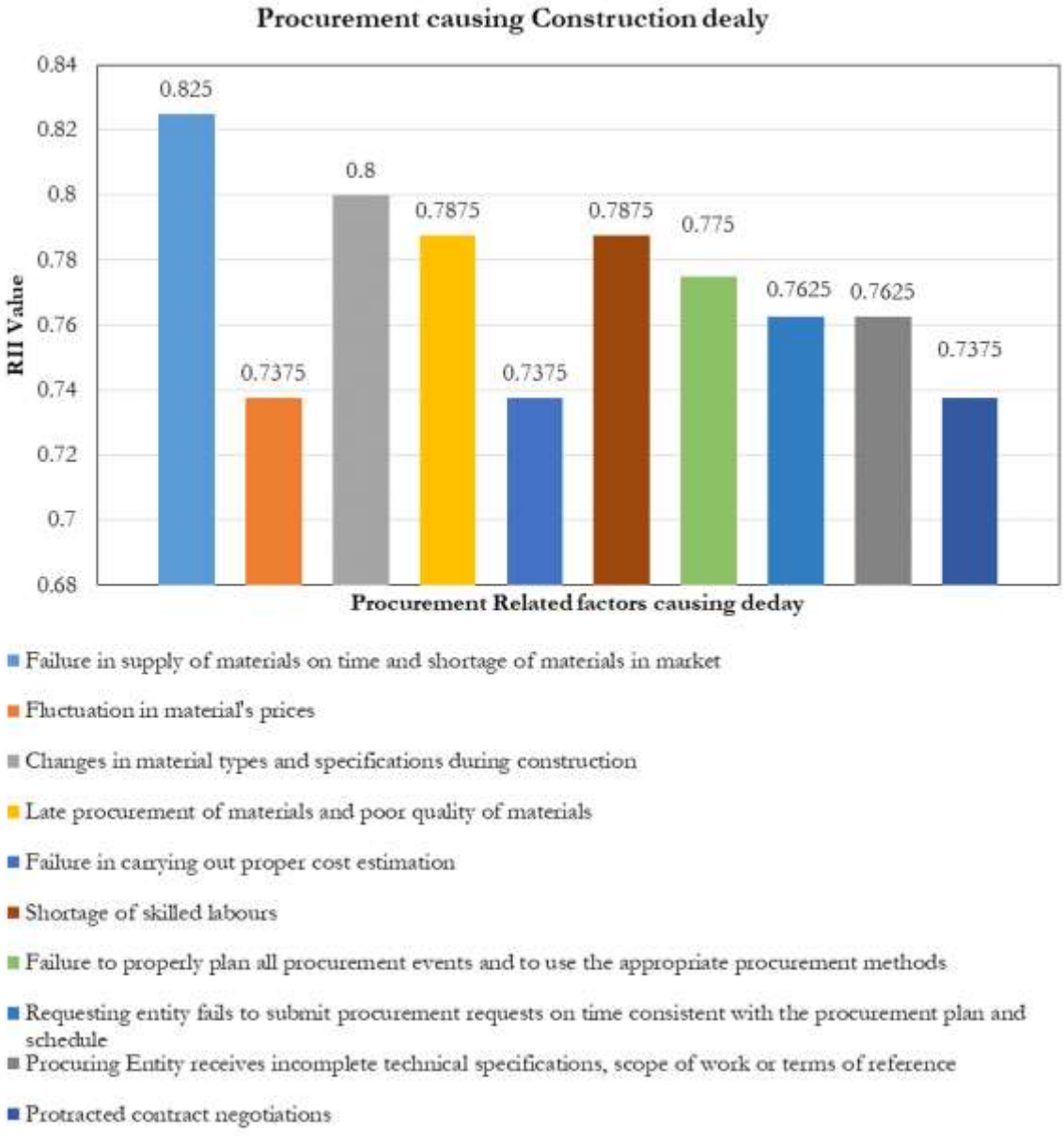

Figure 2. Procurement related factors causing a delay in construction

The graph in figure 2. describes the ranking of materials and procurement related factors contributing to a construction delay. On analyzing the factors by calculating their RII value and on ranking them, it was noted that of the twenty-four (24) factors, the top five factors with their crucial contribution to delay are a failure in the supply of materials on time and shortage of material

in the marketplaces (RII=0.825), changes in material types and specifications during construction time (RII=0.8), late procurement of materials and poor quality of materials (RII=0.7875), shortage of skilled labours (RII=0.7875) and failure to properly plan all procurement events and to use the appropriate procurement methods (RII=0.775).

Crucial factors causing delay

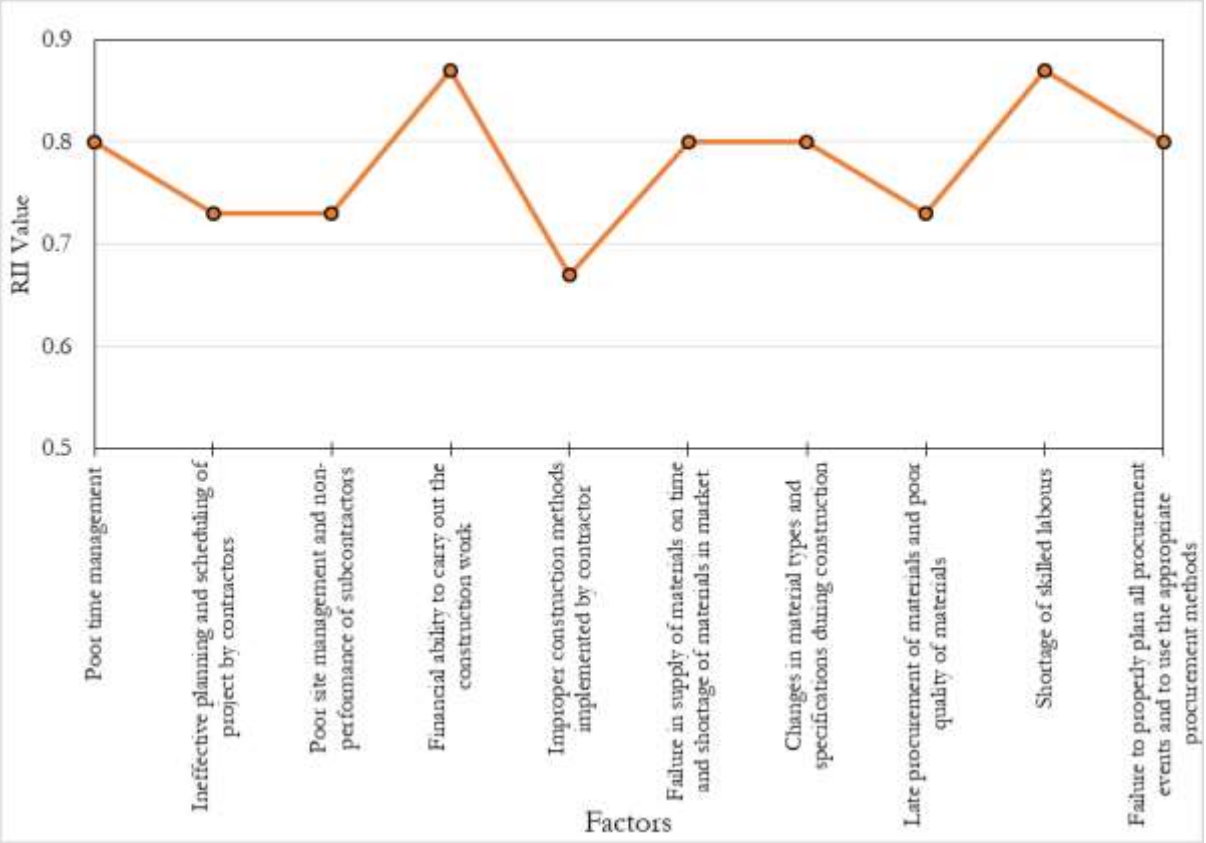

Figure 3. Crucial factors causing delay in construction from case study

The above figure 3. describes the ranking of the top ten factors contributing to construction delay which is obtained from the civil related and materials and procurement-related questionnaire survey distributed among civil engineers and the procurement managers. As per the viewpoint of the project managers and engineers working, the five crucial factors contributing grossly to delaying construction project are; Financial ability to carry out the construction works (0.87), Shortage of skilled labourers (RII=.87), Poor time management (RII=0.8), Failure in the supply of materials on time and shortage of materials in the market (RII=0.8) and Changes in material types and specifications during construction (RII=0.8). The graph in the figure clearly shows the comparison of the factors concerning their RII value. The factor with a higher value of RII is ranked at the top as the most principal factor affecting the period of the construction project. The factors which are having the least RII value (i.e., Inappropriate construction methods practiced by

contractor, RII=0.67) is ranked the last, which states it has very less effect on the time duration of the construction project.

Measures to minimize delay

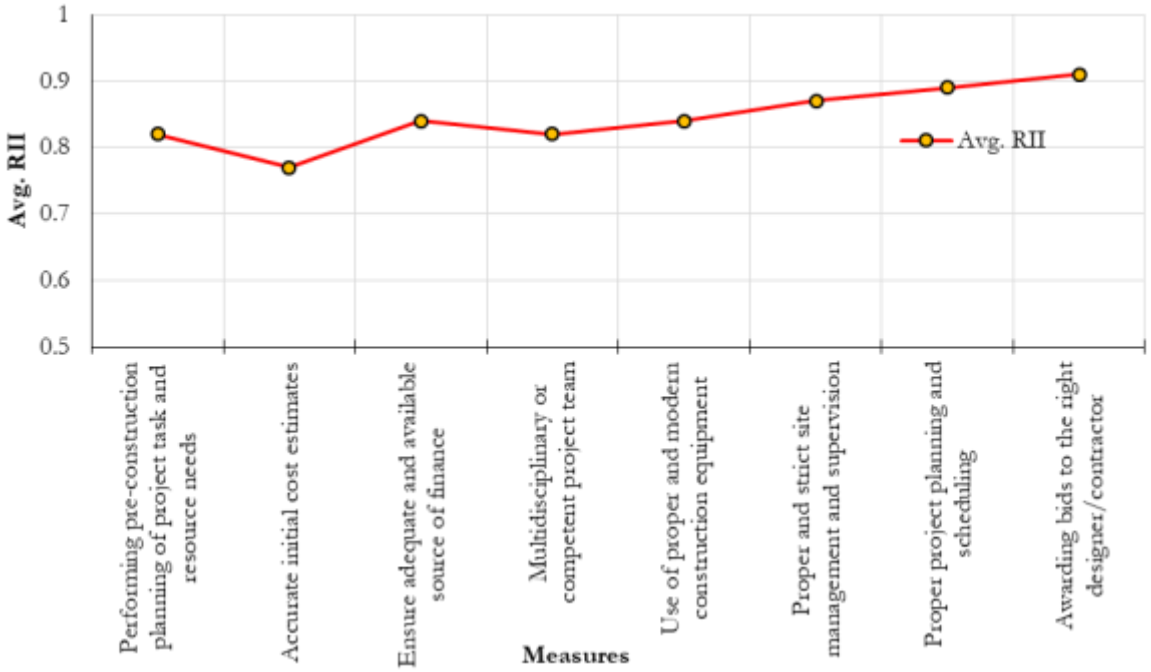

Figure 4. Top four effective methods of minimizing delay.

The above graph in figure 4. shows the calculation of the average RII value for the measures to minimize construction delay. The average of the RII value obtained from the questionnaire survey distributed to civil engineers and procurement managers and from the case study done vie interview questions, we have come out with the most suitable and effective methods of controlling construction delay in the Bhutan. The final top four measures are; Awarding bids to the right designer/contractor (RII=0.91), Proper project planning and scheduling (RII=0.89), Proper and strict site management and supervision (RII=0.87) and Use of proper and modern construction equipment (RII=0.84). The graph in the figure shows the comparative analysis of the various methods that could help reduce future delays in any construction project if adopted correctly. The result displayed in the graph is based on the average RII value. The measure to minimize delay, it should be culmination of all factors with more focused on the 'awarding bid to the right designer andcontractor'.

When interviewing the project managers and engineers working in the construction of Dewathang hospital, it was found that the MS-Project is the most commonly used software for scheduling construction work activities and estimating the time required for completion. In the work schedule of the hospital that we have prepared, the time duration estimated for completion is approximately two years with two months of additional times for preparatory.

Conclusion

To summarize, the factors causing delays in construction projects were pointed out and ranked based on the Relative Importance Index from the valuation made by the project managers, procurement officers and civil-engineers. From the analysis part, the top five factors with the highest rank are related to the financial ability to carry out the construction work; shortage of skilled labours; poor time management; failure in the supply of materials on time and shortage of materials in the market; and changes in material types and specifications during project constructions.

This study also concluded that various measures such as awarding bids to the right contractor; proper and strict site management and supervision; proper project planning and scheduling; and use of proper and modern construction equipment are to be adopted to avoid delay of construction projects in the region. Moreover, the researchers have suggested the construction firms to adopt the MS Project software which might determine the project duration.

Acknowledgement

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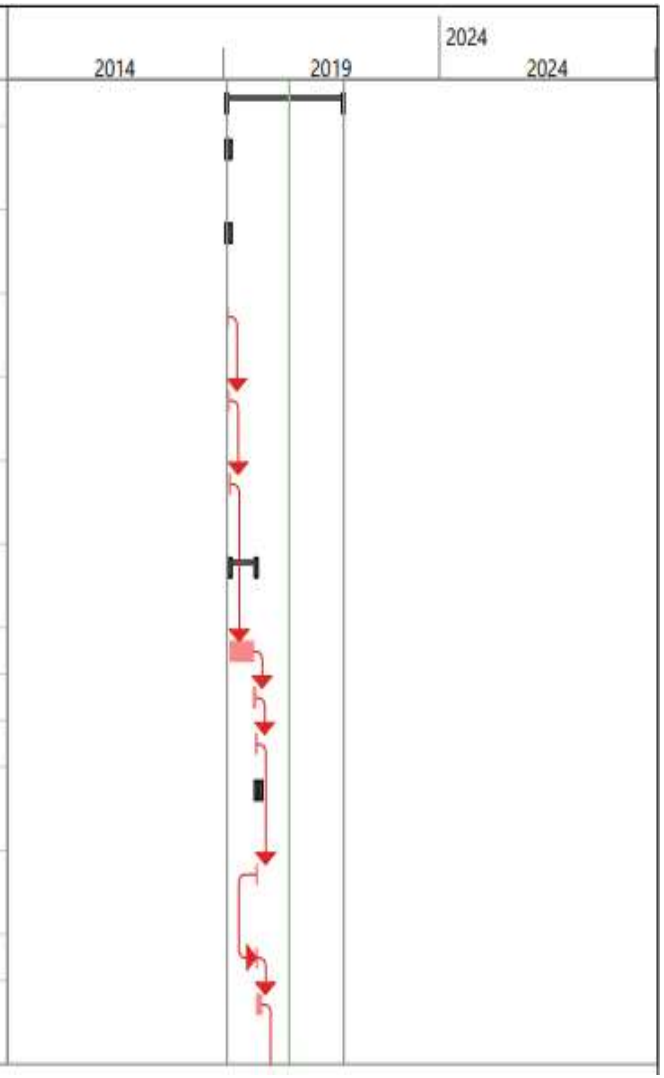
Conflict for interest: The authors declare no conflict of interest.

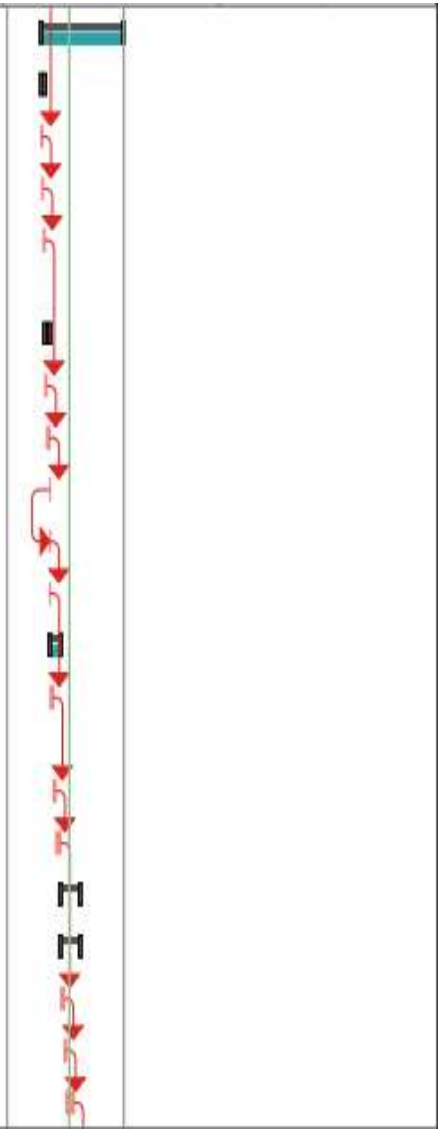
Appendix A

Table 1: Determination project time duration using MS-Project

ID	Task Mode	WBS	Task Name	Duration	Start	Finish
1		**1**	**Total Duration**	**704 days**	**Fri 01/02/19**	**Wed 13/10/21**
2		**1.1**	**Bid Procurement and Tendering**	**18 days**	**Fri 01/02/19**	**Tue 26/02/19**
3		**1.1.1**	**Contractors Pre-qualification**	**18 days**	**Fri 01/02/19**	**Tue 26/02/19**
4		1.1.1.1	Receiving Pre-qualification	6 days	Fri 01/02/19	Fri 08/02/19
5		1.1.1.2	Analysis of Pre-qualification	6 days	Mon 11/02/19	Mon 18/02/19
6		1.1.1.3	Selection of pre-qualified	6 days	Tue 19/02/19	Tue 26/02/19
7		**1.2**	**Contractors qualification**	**159 days**	**Wed 27/02/19**	**Mon 07/10/19**
8		1.2.1	Tender Floating	140 days	Wed 27/02/19	Tue 10/09/19
9		1.2.2	Tender analysis	14 days	Wed 11/09/19	Mon 30/09/19
10		1.2.3	Tender Negotiation	5 days	Tue 01/10/19	Mon 07/10/19
11		**1.3**	**Contractor award Recommendation**	**31 days**	**Tue 08/10/19**	**Tue 19/11/19**
12		1.3.1	Contract Terms and condition	1 day	Tue 08/10/19	Tue 08/10/19
13		1.3.2	Award of contract	1 day	Tue 08/10/19	Tue 08/10/19
14		1.3.3	Labours and Materials	30 days	Wed 09/10/19	Tue 19/11/19



15		**1.4**	**Execution/Construction**	**496 days**	**Wed 20/11/19**	**Wed 13/10/21**
16		**1.4.1**	**Preparatory works**	**21 days**	**Wed 20/11/19**	**Wed 18/12/19**
17		1.4.1.1	Mobilazation	1 day	Wed 20/11/19	Wed 20/11/19
18		1.4.1.2	site clearance	10 days	Thu 21/11/19	Wed 04/12/19
19		1.4.1.3	site layout and Preparation	10 days	Thu 05/12/19	Wed 18/12/19
20		**1.4.2**	**Sub structure**	**30 days**	**Thu 19/12/19**	**Wed 29/01/20**
21		1.4.2.1	Earthwork	10 days	Thu 19/12/19	Wed 01/01/20
22		1.4.2.2	Excavation	18 days	Thu 02/01/20	Mon 27/01/20
23		1.4.2.3	Levelling	2 days	Tue 28/01/20	Wed 29/01/20
24		1.4.2.4	Backfill	1 day	Tue 28/01/20	Tue 28/01/20
25		1.4.2.5	Disposal	1 day	Wed 29/01/20	Wed 29/01/20
26		**1.4.3**	**Foundation**	**65 days**	**Thu 30/01/20**	**Wed 29/04/20**
27		1.4.3.1	Stub columns and footings	20 days	Thu 30/01/20	Wed 26/02/20
28		1.4.3.2	Plinth beams	15 days	Thu 27/02/20	Wed 18/03/20
29		1.4.3.3	Shear wall	30 days	Thu 19/03/20	Wed 29/04/20
30		**1.4.4**	**Super Structure**	**119 days**	**Thu 30/04/20**	**Tue 13/10/20**
31		**1.4.4.1**	**Structure element**	**119 days**	**Thu 30/04/20**	**Tue 13/10/20**
32		1.4.4.1.1	Ground slab	20 days	Thu 30/04/20	Wed 27/05/20
33		1.4.4.1.2	Columns	15 days	Thu 28/05/20	Wed 17/06/20
34		1.4.4.1.3	Walls	45 days	Thu 18/06/20	Wed 19/08/20



35		1.4.4.1.4	Roof slab	25 days	Thu 20/08/20	Wed 23/09/20
36		1.4.4.1.5	Beams	14 days	Thu 24/09/20	Tue 13/10/20
37		**1.4.5**	**MEP works**	**77 days**	**Wed 14/10/20**	**Thu 28/01/21**
38		1.4.5.1	Wirings	15 days	Wed 14/10/20	Tue 03/11/20
39		1.4.5.2	Electrical appliances	20 days	Wed 04/11/20	Tue 01/12/20
40		1.4.5.3	Circuit Breaker installation	10 days	Wed 02/12/20	Tue 15/12/20
41		1.4.5.4	Piping	12 days	Wed 16/12/20	Thu 31/12/20
42		1.4.5.5	Sanitary Fittings	20 days	Fri 01/01/21	Thu 28/01/21
43		**1.4.6**	**HVAC**	**19 days**	**Fri 29/01/21**	**Wed 24/02/21**
44		1.4.6.1	Ducting	9 days	Fri 29/01/21	Wed 10/02/21
45		1.4.6.2	Equipment fittings	10 days	Thu 11/02/21	Wed 24/02/21
46		**1.4.7**	**Finishing**	**165 days**	**Thu 25/02/21**	**Wed 13/10/21**
47		1.4.7.1	Block Masonry	30 days	Thu 25/02/21	Wed 07/04/21
48		1.4.7.2	Doors/Window frar	35 days	Thu 08/04/21	Wed 26/05/21
49		1.4.7.3	Plastering	15 days	Thu 27/05/21	Wed 16/06/21
50		1.4.7.4	Doors/window pan	30 days	Thu 17/06/21	Wed 28/07/21
51		1.4.7.5	Flooring and Tiles	25 days	Thu 29/07/21	Wed 01/09/21
52		1.4.7.6	Paints	30 days	Thu 02/09/21	Wed 13/10/21

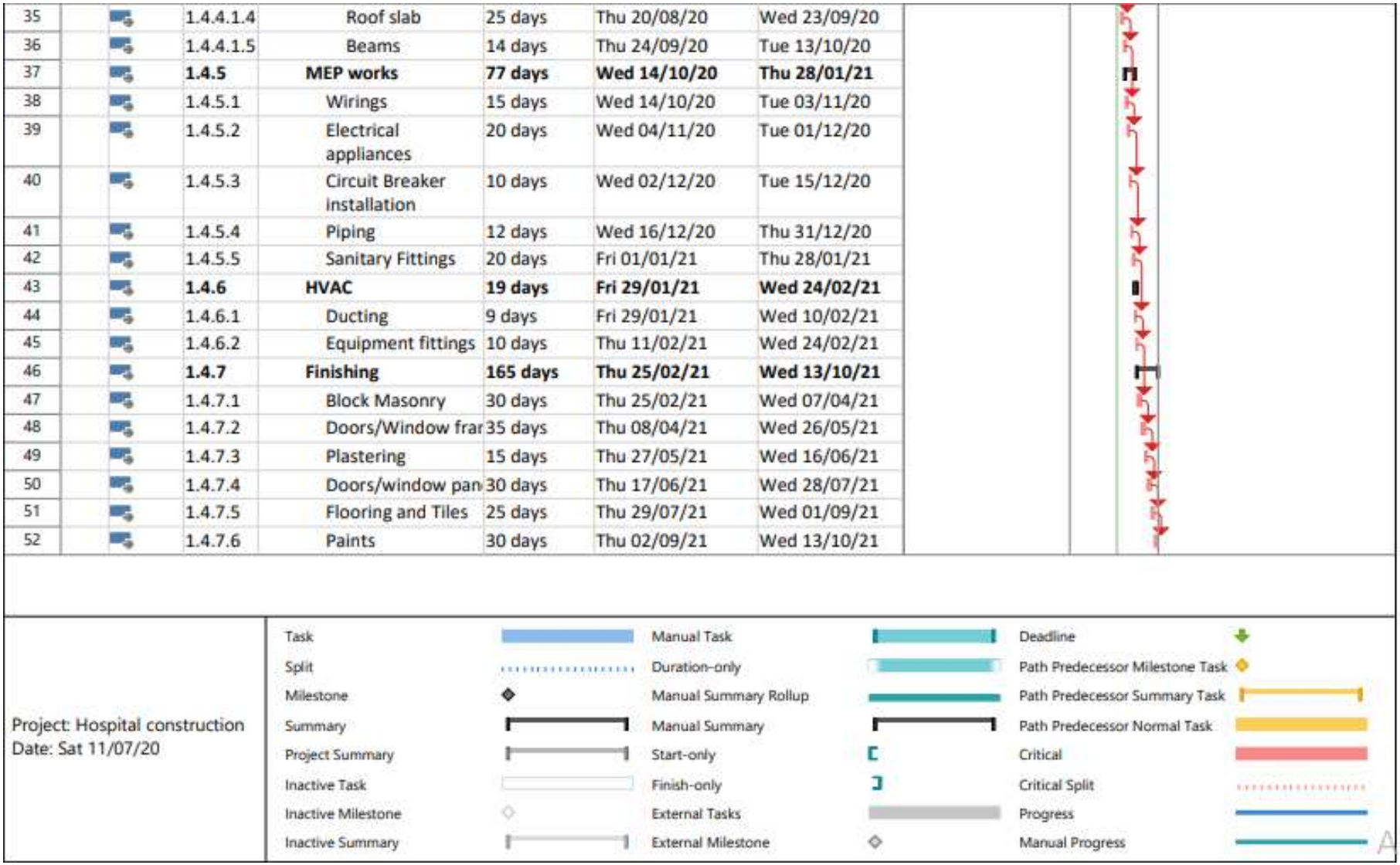


Figure 5. work schedul in MS-Project

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Design and Construction of Prestressed Concrete Bridge in Himalayan Terrain - experiences from Dechencholing Bridge in Bhutan

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Abstract: The paper highlights the method of construction adopted for the construction of prestressed concrete bridge at Dechencholing over river Wangchu in Thimphu, Bhutan. A single span 30m long prestressed concrete bridge was design replacing the old deteriorated bailey bridge which was built in 1960s. The bridge was design to carry IRC 70-R class loading. The superstructure was prestressed concrete beam girder with RCC deck. The substructure was inverted T-type RCC abutment which were restrained by wing walls. The total cost incurred for the construction of bridge was Nu. 40.135 million. The construction of bridge was started in February 2015 and completed in May 2016. The design of the bridge was based on the principle of durability and low maintenance cost during its life cycle. Besides, the objective of this paper is to account the technical record on construction of Dechencholing bridge which will help engineers in assessing the constructed bridge for rehabilitation and replacement in the future. The paper also aims to provide some insight of the bridge construction in the Himalayan terrain for the practicing profession on the method adopted and improve on methods while constructing the future bridges.

Keywords: Bridge, prestressed concrete, geotechnical investigation, construction

Introduction

The concept of a bridge is one of the oldest ideas of mankind brought about by the requirement of crossing an obstruction. The first bridge was probably made by spanning small steams with the help of fallen trees. The simply supported bridge using stone, timber and brick materials were commonly used until mid-ninetieth century. The subsequent evolution of bridge engineering in the 21st century resulted in improvement of structural form with clear understanding of structural analysis and design, coupled with improved construction materials and methods of fabrication and erection (Raina, 2010).

In Bhutan, the modern bridge construction started with technical degree of maturity like the rest of the world from 1960. The most common bridges constructed in Bhutan today are steel bailey bridge and reinforce cement concrete bridge. One of the more recent materials used in bridge construction is prestressed concrete due to its economical span and widely used all over the world. This paper therefore aims to present the method adopted for the construction of

prestressed concrete bridge involving feasibility study, design and construction through a case study from the construction of Dechencholing bridge. The design of the bridge was based on the principle of serviceability, safety of the structure, durability of structure, achievability of the construction quality, ease of maintenance, environmental compatibility and economy [Department of Roads, 2015].

Besides, the objective of this paper is to account the technical record on construction of Dechencholing bridge. Many bridges have been built in the past in Bhutan and there is no record to study the life cycle of the bridge. This makes decision makers and engineers difficult in assessing the constructed bridge for rehabilitation and replacement. The paper aims to facilitate the assessor for rehabilitation of the bridge in the future. The paper will also provide some insight of the bridge construction in the Himalayan terrain to the engineering students and practicing profession on the method adopted and improve on methods while constructing the future bridges.

Background

Dechencholing bridge is located at 7 km to the north of the Thimphu city corresponding to 27° 31' 25.60" N latitude and 89° 38' 42.80" E longitude at an elevation of 2320m above mean sea level as shown in Figure 1. The old bailey bridge which was built in 1960s was dilapidated structurally. A permanent bridge was important for the economic growth. The growing population and volume of the traffic flowing over the old bailey bridge had posed great difficulty to the commuters and traffic. The cabinet secretariat and the Thimphu Thromde issued a work order to Construction Development Corporation Limited (CDCL) to design and construct a permanent bridge replacing the old bailey bridge.

The project on construction of Dechencholing bridge was based on design and build model. The project started with feasibility study, design and construction. The feasibility study carried out were evaluating project benefits, timeframe, resources requirement and cost. The prerequisite for designing of bridges were identified and studied such as catchment study, discharge, linear waterway, scour depth, sub-soil investigation, bearing capacity and loading condition. The construction started with construction of abutment, placing of bearing, longitudinal girder, cross girder and deck slab. New construction technology on post tensioning which is special form of prestressed concrete were adopted in the construction of girder. The record of resources gone into the construction of bridges in terms of materials, manpower, machinery and cost were reflected to provide idea for future planning and construction.

Figure 1: Location of Dechencholing bridge (Source; earth. google.com)

Feasibility Study

The feasibility study forms and important part of the design. The feasibility study was carried out for design suitability, construction, accessibility, cost and completion schedule. The preliminary study on various types of bridge foundation and structure with reference to site condition and time schedule were explored.

The alignment forms an important part of the bridge in blending with highway and surrounding environment. The existing highway and old bailey bridge alignment were selected. The preferred location of the bridge was at a distance of 20m on the downstream side of the old Bailey bridge at an elevation of 2308m to maintain level with the existing highway. The Figure 2 shows the propose location of new bridge.

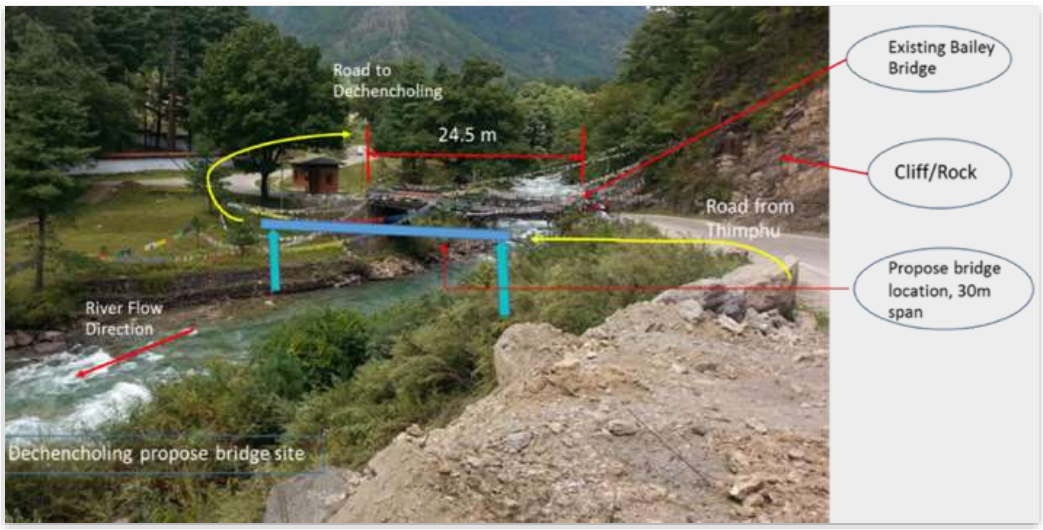

Figure 2: The propose location of new bridge

Table 1: Salient features for design considerations from feasibility study

Sl. No.	Design Parameters	Units	Particulars
1	Propose bridge location		20m downstream of the old bailey bridge
2	Elevation at road level	m	2308
3	Lowest flood level	m	2300
4	Highest flood level	m	2302
5	River bed level	m	2298
6	Span of bridge	m	30
7	Type of loading	IRC	70R
8	Type of superstructure	Option 1	Steel Girder with RCC deck bridge
9		Option 2	PSC box Girder bridge
10		Option 3	RCC Arch bridge
11	Bearing capacity	t/m^2	50 (assumed)
12	Carriageway width	m	7m width 1.5m footpath on both side
13	Concrete grade		M25, M30, M35
14	Timeline	Option 1	12 months
15		Option 2	14 months
16		Option 3	16 months
17	Advantage	Option 1	Fast construction
18		Option 2	Less expensive
19		Option 3	Aesthetically sound
20	Estimated cost	Option 1	Nu. 1.118 million/m
21		Option 2	Nu. 0.983 million/m
22		Option 3	Nu. 1.162 million/m
23		Site development	Nu.16.070 million

Figure 3: Comparison of turning radius of old bridge and propose bridge location

The propose location had the advantage of having enough working space during construction. There was no interruption to existing traffic during construction. The left bank rock excavation was avoided to save the cost and reduce the noise pollution from blasting. The old bailey bridge abutment at the upstream was used as river retaining structure and there was good turning radius for vehicles as shown in Figure 3. The brief summary of the feasibility study is mention in Table 1.

Hydraulic Study

The sub soil investigation and hydraulic study was important prior to the design of bridge. The geotechnical investigation includes mechanical boring and general investigation on geology present at the bridge location. The hydraulic study includes watershed mapping to calculate the total catchment area, the rainfall-runoff and the river discharge analysis using different methods. The hydraulic study was used to determine the High Flood Levels (HFL), Low Water Levels (LWL), linear waterway and design discharge. The hydraulic study and sub soil investigation were outsourced to Kalachakra Consultancy Services.

Catchment Study

Hydrological and metrological data of rainfall, wind speeds & directions, temperature, water discharge were obtained from the Hydromet Services Department, Ministry of Economic Affairs. The hydrological analyses of rainfall and runoff data were required to establish relationships between flood flow and flood frequency for hydraulic design. The collection of the hydraulic data was based on guidelines provided in IRC: 5-1998 Clause 102.3.

It was observed that the whole of Thimphu district was covered by the Wangchu basin. Wangchu is a major river and flows towards south easterly direction cutting its path through the steep mountain slopes forming deep and narrow gorges. The total catchment area for Dechencholing bridge was approximately 527 km^2. The terrain was mostly mountainous with rugged terrains. The catchment area slope ranges from 10° to as high as 80° (Kalachakra Consultancy Services, 2015).

Discharge

The bridge site experiences a sub-tropical climatic condition with maximum rainfall concentrated in the months of June to September (Department of Hydro-Met Services, 2011). A maximum flood discharge of 100 years return cycle was considered for the design discharge. The maximum discharge was determined using different methods namely; available records of the river at the bridge site, rainfall and other characteristics of the catchments and the area velocity methods.

The simplest and the most frequently used rainfall-runoff technique is the Rational method. The peak discharge was 448 m^3/s using Rational method (Q = 0.277CIA where Q is peak discharge, C is the runoff coefficient, I is the intensity, A is the catchment area in km^2). The peak discharge is 434 m^3/s using Gupta Modified Rational method ($Q = 640 X PRAe^{x.}$ where x = 0.92 + 1/42. log Ae, Q is peak discharge, P is average area rainfall, R is runoff coefficient, Ae is effective catchment area). The peak discharge is 975.3 m^3/s using Empirical Discharge-area method using Williams Equation ($Q m = 12.13A^{0.70}$, where Q m is the Peak discharge, A is the catchment area in km^2).

The maximum design discharge at the Wangchu bridge using the Velocity-Area method was 674.5 m^3/s with 1.90 m/s velocity. However, the velocity of the river increases as the river volume increase and it was estimated that the velocity reaches 4.0 m/s during which time the maximum discharge was 1420 m^3/s.

Linear Waterway

Since the bridge falls in a Himalayan region where the meandering of the rivers and stream was restricted by the steep topography and the occurrence of the surface or near surface bed rocks, the linear waterway which was the distance between banks at the water surface elevation should allow the maximum discharge without creating harmful afflux. Study was carried out at 100m distance both upstream and downstream of the river to find out siltation, gradient of the river, characteristics of the bed materials, scouring effects of the flood, water surface slope, and probable artificial blocking of the channel by landslides. As per IRC: 5-1998 Clause 101.8, the linear waterway is 21m for this discharge and thus, the proposed bridge span of 30m was sufficient.

Scour Depth

Scours occur when the bed velocity of the river exceeds the velocity which can move the particles of the bed materials. The velocity varies with the gradient, the hydraulic mean depth and the character of the bed and banks. The scouring action was not uniform all along the bed width. Therefore, the mean depth of the scour was calculated as per the guidelines given in IRC: 5-1998 Clause 110.1.3. The mean depth of scour obtained was 8.71m considering 674.5 m^3/s of design discharge and 21m of linear waterway. The Table 2 shows the mean scour depth calculation.

Sub Soil Investigation

The sub soil investigation was carried out by drilling in accordance with the guidelines provided in IS: 1892 – 1979: "Code of Practice for Subsurface investigation for Foundations". There were two types of engineering materials found at the bridge location. They were alluvial

deposit from the river forming the low-lying flat areas usually formed by the river and the gneissic bed rock. The river bed material consists of sand and boulders of pegmatite, grey, fine grained hard and compact quartzite, medium grained light-colored micaceous quartzite, biotite schist and biotite gneiss with few quartz gravels. They were rounded to sub rounded and sizes vary from boulders to gravels. The gneissic bed rock was moderately weathered with occasional quartz boudins. It was dark greyish to brownish colored and fine grained (Kalachakra Consultancy Services, 2015). The Figure 4 shows the bed rock exposure at bridge location.

Table 2: Mean scour depth calculation

Sieve size	Wt. retained	% retained	Avg. sieve size	% retained X Avg. sieve size
200	0	0	175	0
150	0	0	112.5	0
75	0	0	56.25	0
37.5	0	0	28.75	0
20	0	0	14.75	0
9.5	43	6.947	7.12	102.4636
4.75	77	12.439	3.55	88.6308
2.36	21	3.393	1.77	12.0605
1.18	19	3.069	0.89	5.4329
0.6	24	3.877	0.512	3.4507
0.425	29.5	4.766	0.362	2.4424
0.3	84.5	13.651	0.225	4.9485
0.15	216.5	34.976		7.8695
0.075	104.5	16.882		227.2992
	619	100		454.5985
	Weighted mean average (d_m)=		4.55	
	Mean depth of scour =		dsm =	$1.34*(D^2_b/K_{sf})^{1/3}$
			D_b	32.1190
			K_{sf}	3.7525
			dsm	8.7114

The left bank was investigated by drilling a borehole up to 15.10m depth at an angle of 90°. The bed rock was intersected at 14.00m depth in the borehole. The bed rock was moderately to highly weathered biotite gneiss. The high flood level was approximately 3m from the low flood level. The borehole log and sub-soil profile was presented as per the guidelines of IRC 78:2000. The Figure 5 shows the sub soil profile cross section of the borehole and Figure 6 shows the samples of the cores from borehole at left bank.

Figure 4: Bed rock exposure on the right bank

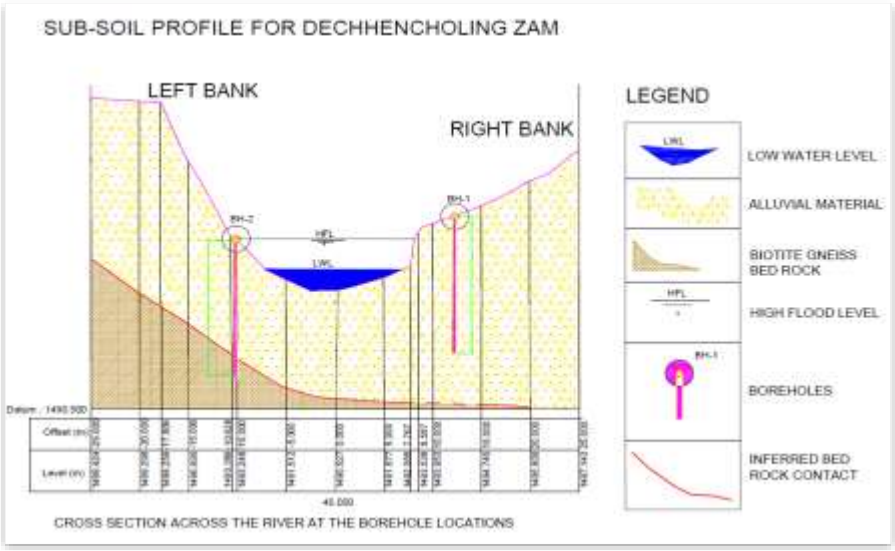

Figure 5: Cross section showing the borehole locations and flood levels

Figure 6: Samples of the cores from borehole at left bank

The right bank was investigated by drilling a borehole to a depth of 15.00m. The Figure 7 shows the sample of cores taken from right bank.

Figure 7: Samples of the cores from borehole at right bank

The other soil test parameter includes grain size analysis of the soil. The sample shows mostly gravelly sand with 74% sand, 18% gravel, and 8% silt. It's Coefficient of uniformity is 3.96 and the coefficient of curvature is 1.34. Therefore, the soil was not distributed in a wide range. It was a uniform soil with bad compaction characteristic. The Coefficient of permeability (k value) or the 20% passing of material from the sieve was 0.14 which correspondingly gives the coefficient of Permeability (k) to be 3.80 X 10^{-3} cm/sec. The soil property falls in a fine-grained sand group. The bridge site had filled material in the interstices of the boulders and therefore the compressibility was expected less (Kalachakra Consultancy Services, 2015).

Bearing capacity

The in-situ rock present was biotite gneiss, which was at 14.00m depth. In its intact form provides over 60 MPa Unconfirmed Compressive Strength (UCS) and tensile strength of over 1 MPa. The bearing capacity obtained was 46.2 t/m^2. The Table 3 shows the bearing capacity calculated.

Design Overview

The span of the bridge was fixed at 30m based on hydraulic study and found to be economical. The length of bridge was kept minimum because of high cost of the bridge structure however, the length could be more if require for aesthetic reasons (Department of Road, 2015). The design was based on the principle of durability and low maintenance cost during its life cycle. The carriage way of the bridge was fixed at 7m and pedestrian foot path at 1.5m on both the sides. The bridge was design with a provisions of service lines beneath the footpath slab. The hand rails were made of glass fiber reinforced concrete with traditional architectural features on it.

The loading condition of the bridge was one of the important factors in designing a bridge. The superstructure design loads consist of dead load (self-weight of the structural components), Superimposed dead load (wearing course and footpath finish), Moving load (class A and Class 70R (W)) as per IRC 6: 2000 standard load, Earthquake load as per section 219 of IRC: 6-2014,

Breaking force as per section 212 of IRC: 6-2014, Pedestrian load as per section 204 of IRC: 6-2014, Wind load on structure as per section 209 of IRC: 6-2014 and Temperature load as per section 215 of IRC: 6-2014. The design load was checked according to clause 202.3 of IRC: 6-2000 on load combination and permissible stresses. The bridge was designed for IRC 70R loading capacity.

Table 3: Determination of bearing capacity at founding strata

Local Shear Failure: (ϕ<28°C, on the basis of angle of shearing resistance)								
Ultimate Bearing Capacity: q_u=2/3c. N'c.Sc.dc.ic+q(N'q-1). Sq. dq. iq+ ½ B.Υ.N'γ.dγ.iγ.W'								
C= cohesion, kpa					0	Modified c and ϕ		
ϕ=internal friction angle in degrees					25	C	2/3c	0
N'c, N'q, N'γ=bearing capacity factors						ϕ	$\tan^{-1}(2/3 \tan\phi)$	25
S_c, S_q, Sγ=shape factors						C=Cohesion, kpa		0
dc, dq, dγ=depth factors						ϕ=internal friction angle in degrees		35
ic, iq, iγ=inclination factors								
Υ=unit weight of the soil, kN/m^2					19	Location PIT -4		
Df=depth of foundation, m					4	Nϕ=$\tan^2(\pi/4+\phi/2)$		
B=width of footing, m					3	$(\pi/4+\phi/2)$		62.5
W=water table correction factor					1	Nϕ		3.69
q=effective surcharge, kN/m^2 (q=Υ.Df)					76	Ultimate bearing capacity	1340.34	kN/m^2
1	N'c	20.72	2	Sc	1.2			
	N'q	10.66		Sq	1.2			
	N'γ	10.88		Sγ	0.6	Allowable safe bearing capacity (Factor of safety of 2.0)	446.779	kN/m^2
3	dc	1.512	4	ic	1			
	dq	1.256		iq	1			
	dγ	1.256		iγ	1	Bearing capacity in tonnes/m^2	46.02	t/m^2
q_u=2/3. c. N'c. Sc. dc. ic+q(N'q-1).Sq. dq. iq+1/2 B.Υ.N'γ.dγ.iγ								
q_u	1340.3356				kN/m^2			

The bridge analysis was done using Midas Civil 2011 software an integrated solution system for bridge and civil engineering in obtaining bending moment and share force. The analysis was done for different components of bridges such as deck slab, cross girder, main girder and substructure.

Wherever possible, the design of bridge has considered the general criteria of simplification in design, reduced number of parts, standardization of common parts and materials, ease of orientation, handling and assembly of parts (Kim et al, 2016).

Construction Techniques

The construction sequences applied for this bridge were: Stage 1- abutment construction; Stage 2- construction of temporary support system for longitudinal girder; Stage 3 -shuttering, re-bar works, cable duct placement, concreting of longitudinal girders, and post tensioning of prestressed cables. Stage 4- construction of cross girders, Stage 5- placing of precast bottom slab to act as formwork for deck slab construction. Stage 6- construction of deck slab. Stage 7- removal of temporary support after achieving the concrete strength of girder and slab. Stage 8- construction of railing, footpath and approach slab. The construction stages of Dechencholing bridge is shown in flow chat Figure 8.

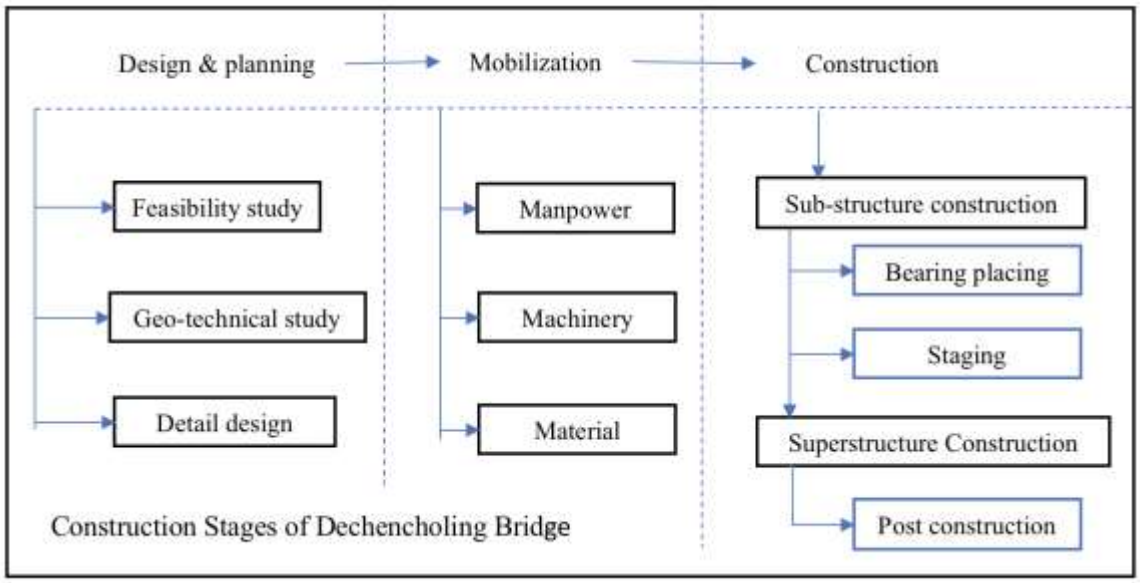

Figure 8. Flow chart of construction stages of Dechencholing bridge

Substructure

The portion of the bridge that supports the superstructure and distributes all bridge loads to bridge footings is substructure. The substructure was inverted T-type abutments which were restrained by wing walls. The height of abutment was 10m. The Figure 9 shows the construction of abutments.

Figure 9: Construction of Abutments

The foundation adopted was shallow open type. The grade of the concrete used was M30. The Table 4 shows the mix proportion of M30 grade of concrete used for Dechencholing bridge. It is observed that the M30 grade of concrete is achieved at a ratio of 1:2.005:2.738 with water cement ratio of 0.43. However, it is important to understand the concrete mix composition factors, for example the type of cement, water to cement ratio, aggregate grade, admixtures and additives for concrete applied, concrete aeration, the consistency of the concrete mix to achieve the desire result (Germaniuk, 2016). The reinforcements used was Fe 500 (fy 500 MPa) as per IS:1786.

Table 4: Mix proportion for M30 grade of concrete

Cement				400	Kg/m^3
Water				172	Kg/m^3
Fine aggregate				802	Kg/m^3
Coarse aggregate (10mm +20mm)				1095	Kg/m^3
Chemical admixture				0	kg
Water cement ration				0.400	
Quantity of coarse aggregates					
water	cement	Fine aggregate	Coarse aggregate Aggregate 10mm	Aggregate 20mm	admixture
172	400	802	329	766	0
0.43	1	2.005	0.823	1.915	0
Final mix proportion					
0.43	1	2.005	0.823	1.915	0

Staging

Staging is a temporary structure usually of timber and steel erected to support the construction of superstructure of the bridge. If the flow of the water is in reasonable limits, the staging may be designed in beam or arch types with footings on water. Some superstructure design such as steel trusses girder and prefabricated reinforced concrete girder do not require staging. In fast flowing rivers or deep gorges where it is not possible to build staging, the form traveller is preferred. In the case of Dechencholing bridge, the precast girder was not possible due to lack of working space. A steel staging was design and built to construct superstructure. The Figure 10 shows the staging erected for construction of superstructure.

Figure 10: Staging for construction of superstructure

Bearing

A bridge bearing is a component of a bridge that is placed between bridge piers and the bridge deck. The bearing carries both vertical and horizontal load of superstructure and transfers to bridge substructure. The elastomeric bearings were designed and used. The bearing is made with a steel plates bonded to the rubber through a vulcanization process to increase the resistance of the bearings to vertical loads and deformation in any direction. The bearings for Dechencholing bridge were manufactured at Mageba Limited, India. The bearing was design based on the AASHTO LRFD, 7th Edition, Method B, Steel Reinforced Elastomeric Bearings, section 17.7.5. The bearing on the left abutment was fixed and on the right abutment was free. The bearing was design with shear modulus of elastomer in the range of 1-1.3MPa with minimum yield strength of steel as fy=240Mpa. The Figure 11 shows the bearing installation on abutments.

Figure 11: Bearing placement on abutment

Superstructure

The superstructure of the bridge consists of longitudinal girder, cross girder, seismic arrestor block, deck slab, connecting slab, kerb beam and railing post. As per design four numbers of I-shaped longitudinal girder were constructed. Each girder was 1.78m depth. The longitudinal girders were RCC prestress and post tensioned with 12-T-13. The longitudinal girders were interconnected by four RCC cross girders placed at an interval of 9.7m c/c. The Figure 12,13 and 14 shows the sequence of longitudinal girder casting.

Figure 12: Fabrication of shutter for longitudinal girder (mid-section, transit and end shutter)

Figure 13: Fixing of platform, reinforcement bar and shutter for longitudinal girder casting

Figure 14: Casting of longitudinal girder and cross girder

Post Tensioning

Post-tensioning is a special form of prestressed concrete in which the prestress tendons are stressed after the concrete attains its preliminary strength. Two extreme ends of the structure are considered as a reaction face, against which the force is applied. Corrugated sheeting ducts are placed inside the formwork along with reinforcement and the concreting is completed. Post-tensioning tendons are usually anchored with mechanical anchorage device. After achieving required concrete strength, a stipulated number of prestressing steels is then inserted in each duct for stressing purpose. After achieving required elongation and stresses they are blocked at two ends with the help of anchor plates and grip which are filled with grout after stressing. This introduces a bonding between the prestressing steel and concrete and any strain experienced by the concrete is experienced by the prestressing steel and vice versa (Rogowsky & Marti, 1996).

The core activities of post tensioning work carried out at Dechencholing were tendon installation, stressing and grouting. The cube strength of the concrete was tested to ascertain the strength of concrete before starting with the actual stressing operations. The stressing operation were initiated after concrete attains its strength between 60% to 80% of its ultimate strength in 28 days. The tendons were sheathed with corrugated HDPE sheath as per IRC: 18 – 2000 with a property to withstand forces likely to act upon it during construction and its service life. The

tendon profile was laid in a smooth parabolic curve between specified control points. The Figure 15 shows the tendon layout profile.

Figure 15: Tendon layout profile in longitudinal girder

The prestressing steel were procured from Usha Martin, manufacturer in India. The manufacturing, supply, testing, cutting and placement of prestressing steel were conformed to Indian Standard IS: 1343, Code of Practice for Pre-stressed Concrete. The prestressing steel used was 7 wires low relaxation strands conforming to IS: 6006-1983 having minimum guaranteed ultimate strength of 1860 MPa.

Anchorage Systems

Prestressing forces of the tendons are transferred to the concrete structures through anchorages. Anchorage for the post tensioning system normally comprises of a steel plates with a number of conical holes, the conical grips and the guide. Guide is used to connect the ducts and provides a flat surface for locating the bearing plate on it (Pre-stressing manual, 2011). The Figure 16 shows the anchorage details.

The strands were inserted into the tendon with 12 strands each. The strands were stressed at the designated ends with the stressing jack in sequence as in design. The stresses in the cables were measured by the extension of the strands and continuously checked by pressure gauge on the jacks. The tendons were tensioned symmetrically about center line of the girder. The initial force applied was equivalent to 139.5KN per strand after seating losses. The grouting of cable ducts was carried out by pressure grouting equipment to fill the void space surrounding the steel. The grout materials used were cement, admixture and water in a water cement ratio of 0.40 to 0.45 by weight.

The Figure 17 shows the post tensioning equipment (stressing jack, pressure pump, grouting pump).

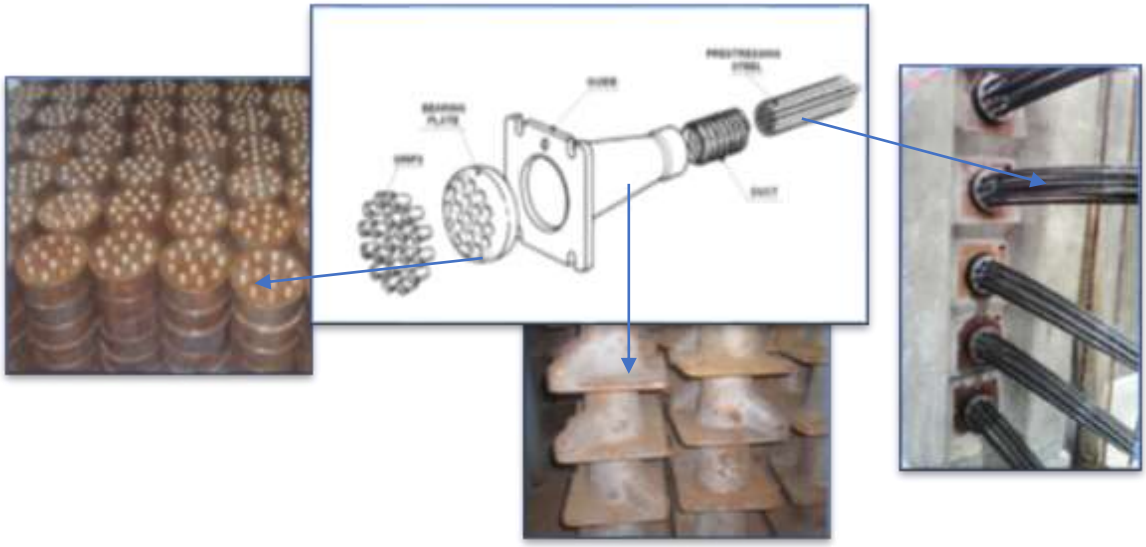

Figure 16: Anchorage details (Photo from Dechencholing bridge site during post tensioning).

Figure 17: Post tensioning equipment (stressing jack, pressure pump, grouting pump).

The grade of concrete used for longitudinal girder, cross girder and seismic arrestor block were M35. The deck slab was 220mm thick with 80mm thick wearing course. The grade of concrete used for deck slab, approach slab, kerb beam and hand railing post were M25. The reinforcement was of high yield strength deformed bars of Fe 500. The schedule of bar was carried out as IS4066:2000. The minimum lap length of reinforcement was conformed to AASHTO/2007. The clear cover for longitudinal girder, cross girder, deck slab, kerb beam and approach slab was taken as 30mm.

The bridge was provided with seismic arrestor block to prevent dislodgement of superstructure during earthquake. The reaction blocks or seismic arrestors was designed for twice the seismic force as per I.R.C.:6-2000, Clause 222.11. The approach slab was constructed to provide a transition between roadway pavement and the bridge. Besides it reduces the settlement of approach embankments caused by consolidation of embankment fills and also reduces dynamic vehicle loads on bridges.

Expansion Joint

To cater for the expansion and contraction of superstructure, TENSA-GRIP Strip Seal Expansion Joint, Type RS-B80 (loop anchorage) with max moving capacity +/- 40mm from Mageba India was provided. The steel for edge beams was conform to the steel grade corresponding to ASTM A36 (A low-carbon steel with excellent fabrication properties) or Canadian Standards Association (CSA) standard G40.21 Grade 300W (This grade is utilized in general fabrication and construction. It also referred to as 300W, which is its metric designation). The edge beam was anchored to the deck by reinforcing bars cast in concrete. The anchorage steel was conformed to IS: 2062. The steel sections were protected against corrosion by hot dip galvanizing coating with a minimum thickness of 100 micron. The Figure 18 shows the strip seal expansion joint.

Figure 18: Strip seal expansion joint.

Drainage Spout

Waterspouts was required to drain out the rainwater from the deck surface quickly. The deck camber helps the rainwater to drain quickly towards kerb. The waterspouts located near the kerb further disposes the water out. One waterspout per 20 sq.m. of the deck area was installed. The drainage spot was fabricated at site. The Figure 19 shows the fabricated drainage spouts at site.

Figure 19: Drainage spouts.

Completed Bridge

The bridge construction took 14 months with additional 2 months for design. The bridge was completed on 20th May 2016 and handed over to Thimphu city. The Honorable Prime Minister of Bhutan inaugurated the bridge on 10th June 2016. The Figure 20 shows completed bridge.

Figure 20: Completed bridge

Proposed Landscaping

The site development works includes river protection and landscaping works. The river protection work was accorded priority over landscaping due to limited budget. However, the bridge being within the vicinity of city and Royal palace, the landscaping is proposed as shown in Figure 21 to improve the aesthetic of the bridge. The Thimphu city plans to take up landscaping work in the future.

Figure 21: Proposed landscaping of bridge site.

Maintenance

The periodic maintenance of the bridge forms and important part of the bridge to serve its indented purpose over the life cycle of the bridge. However, beautiful the bridge be constructed, if the maintenance is not given due importance, the bridge will be deteriorated in short time. The consequences of delay in periodic and preventive maintenance will result into higher maintenance cost, accident and even bridge failure. The key maintenance for the bridge are cleaning of the deck surface, cleaning of drainage spouts, painting of hand railing, cleaning bearing and expansion joint area from spill oil and debris, resurfacing of wearing course and re-road marking, preventing lifting of materials from upstream and downstream of bridge and diverting storm water.

Resources

The important factors that contribute to the success of project includes providing resources as per project schedule. The resources were broadly classified into four categories namely manpower, machinery, material and financing. Besides, the success of the project also depends on implementing robust project management techniques in areas such as the planning, control of time, cost and quality.

Manpower

The workforce involved were all Bhutanese consisting of daily workers and employee under guaranteed employment program roll out by Ministry of Labour & Human Resources. The maximum workers deployed in a month was 40 numbers. The total expenditure for the manpower engagement from Feb. 2015 to May 2016 was Nu. 6,054,663.00 (Nu. 3,526,300-MR, Nu.

1,294,000- GEP, Nu. 1,210,655-Overtime). The average expenses per month on workers was Nu. 378,416.44 (CDCL, 2016).

Machinery

The major machinery involve during construction were earth moving machines such as excavator, backhoe and truck. The Table 5 indicates the cost incurred for the machines during the construction. The percentage indicate that the bridge has deployed 54% government own machinery and 46% private machinery through hiring, thereby giving equal opportunity for the development of private sector (CDCL, 2016). Table 6 indicates the cost incurred for the inventories during the construction. It is observed from the amount that the maximum cost incurred for such bridge construction is on staging items.

Table 5: Machinery engaged.

Sl. No.	Agency	Amount (Nu.)	Percentage
1	CDCL (central Region)	1,479,581.59	27%
2	CDCL (Western Region)	1,334,036.52	25%
3	Private firms	2,435,048.70	46%
4	CDCL (Phuntsholing fleet)	87,246.92	2%
	Total cost	5,335,913.73	

Table 6: Inventories.

Sl. No.	Particulars	Amount (Nu.)
1	Office stationaries	118,020.80
2	Pre-stressing equipment	824,372.50
3	Plants and equipment	384,272.74
4	Hand tools	41,875.75
5	Safety gears	34,512.50
6	Staging items (ISMB & support jacks)	3,927,851.10
		5,330,905.39

Materials

The major materials consumed were sand, cement, aggregate, reinforcement steel bar, timber, ply board, CGI sheet, roll steel, bitumen, boulder and hard ware items. The volume of concrete procured as Ready-Mix Concrete (RMC) was 577cum (456cum was of concrete grade M30 and 122cum was of concrete grade M35). The total of 75 MT of reinforcement and 6MT of

pre-stressing cables were used. The GRC hand rails of 73m length was procured and installed. The Table 7 shows the consumption of major materials. The percentage from Table 6 indicate that maximum construction material used is concrete which is 11%. This is due to the natural and type of bridge material selected during design phase.

Table 7: Construction materials consumed.

Sl. No.	Particulars	Amount	%	Sl. No.	Particulars	Amount	%
1	Ready Mix Concrete	4,001,335.00	28%	5	Bridge parts	1,576,114.16	11%
2	Imprest fund	436,144.00	3%	6	Hardware items	818,943.65	6%
3	Pre-stressing items	1,405,743.00	10%	7	Boulders	241,910.56	2%
4	Staging items	5,276,211.70	37%	8	Miscellaneous	435,531.74	3%
Total cost of construction materials: Nu. 14,191,983.81							

Financial

The total expenditure incurred for the construction of Bridge was Nu. 40,135,267.68. However, the project was left with balance material and equipment worth Nu. 2,382,140.00 (CDCL, 2016). The Table 8 shows the details of expenditure breakup. It is observed that the maximum project expenditure is on construction materials which is 35% followed by worker's payment 16%.

Table 8: Abstract of the project expenditure

Sl. No.	Expenditure statement	Amount (Nu.)	Percentage (%)
1	Construction materials	14,191,983.81	35
2	Hire charges	5,335,917.27	13
3	Workers payment	6,392,503.90	16
4	Staff salary	2,824,141.53	7
5	Raw materials	4,972,621.26	12
6	Maintenance and fuel	1,231,829.10	3
7	Miscellaneous	5,186,270.81	13
	Total expenditures	40,135,267.68	100
8	Stock balance	1,771,936.66	
9	Girder shutter plates	610,203.64	
	Total stock balance	2,382,140.30	

The manufacturing, supply and installation of traditional Bhutanese style GRC railing in plain design with bay size 1760mm x 1180mm with 980mm height with 3 number of post cost Nu. 5,500 per running metre. The hand railing was procured from GRC Jemina, Bhutan.

The prestress cable and equipment were procured from Usha Martin Limited, India at a total cost of Nu. 1,800,861.00. The detail cost break for pre-stress components are mention in Table 9.

Table 9: Pre-stress components and cost.

Sl. No.	Description of items	Unit	Qty.	Rate (Nu.)	Amount (Nu.)
1	12T13 bearing plate	No.	52	370	19,240.00
2	½" anchorage wedges (2 segments)	Pair	655	29	18,995.00
	Total				38,235.00
	Add excess duty @12.50%				4,779.38
	Total				43,014.38
	Add central sales tax @ 14%				6,022.01
	Total -A				49,036.39
3	12.7mm LRPC strand	MT	6	48,500	291,000.00
4	1800MG Jack with VMP 3/2 Pump	Set	2	485,000	970,000.00
5	Grout Pump	No.	1	115,000	115,000.00
6	Grout Agitator	No.	1	45,000	45,000.00
7	12T13 Hollow Profile cast iron (Anchor Cone)	No.	52	580	30,160.00
	Total				1,451,160.00
	Add central excise duty @ 12.50% except item no.7				177,625.00
	Total				1,628,785.00
	Add central sale tax@5%				81,439.25
	Total				1,710,224.25
Add freight: 1no 16-ton capacity truck load @ Nu. 2600/- per ton up to Jaigoan, WB					41,600.00
	Total-B				1,751,824.25
	Grand total (A+B)				1,800,861.00

The shutter for longitudinal girders were fabricated with materials procured from local market. The total cost incurred was Nu. 11,256 per each plate. The details cost break is mention in Table 10.

Table 10: Girder shutter and cost.

Sl. No.	Types of plates	Specifications	No. of plates	Units

1	Anchorage plates	1800mmx350mm	4	No.
2	End plate	1800mmx1260mm	8	No.
3	End plate	1800mmx740mm	1	No.
4	End plate	1800mmx700mm	3	No.
5	Transit plate	1800mmx1040mm	8	No.
6	Mid-section plate	1800mmx1260mm	84	No.

Shutter fabrication

Sl. No.	Descriptions	Quantity	Rate (Nu.)	Amount (Nu.)
1	MS plate 1.26x2.4m, 4mm	10MT	40,500	405,000.00
2	MS flat, 40mm x 4mm thick	3.3MT	41,000	135,300.00
	Cost of transportation	2 truck loads	40,828	40,828.00
1	Material used per plate			
2	Electrode	1.5	525	85,050.00
3	Grinding wheel	2	41	8,856.00
4	Cutting wheel	0.25	92	2,484.00
5	Oxygen gas	0.167	714	12,892.13
6	DA gas	0.1	2,277	24,593.76
7	Supervisor	1	700	75,600.00
8	Skilled worker	4	400	172,800.00
9	Unskilled worker	6	300	194,400.00
	Cost for fabrication			1,157,803.89
10	Tools/plants and electricity	5%		57,890.19
		Total cost		1,215,694.09
		Cost per shutter plate		11,256.43

The elastomer bearing and strip seal expansion joint were procured from Mageba Limited, India. The cost will vary as per the design requirement, brand of the manufacturer and market situation. The cost is shown in Table 11.

Table 11: Bearing and expansion joint cost.

Sl. No.	Description	Code (GST)	Unit	Qty.	Rate (Nu.)
1	Elastomeric bearings of size 500x350x106mm	7308	EA	4	13,000
2	Elastomeric bearings of size 400x250x90mm	7308	EA	12	6,300
3	TENSA GRIP Strip expansion joint type RS-880 with max. moving capacity +/- 40mm	7308	m	36.310	5,500
4	Freight cost	9965	LS	1	80,000

Conclusion

An attempt has been made in this paper to disseminate information on the method statement for design and construction of prestressed concrete girders bridge based on the experiences gained during the construction of this bridge. The following lessons were recommended to consider for planning of future bridge construction.

- The success of the project depends on following proper technical procedure and system during construction such as work and resources scheduling, maintaining quality and safety, optimum utilization of resources, minimizing delay and constant monitoring.
- The feasibility study with design options is important to present to the planners and decision maker for making decision on selection on bridge type to be constructed which ultimate guides the budget of the project.
- The determination of a reasonably accurate soil profile through subsoil investigation and hydraulic study at the propose bridge site is essential for the correct decision on the location and the type of foundation and span of bridge which ultimately decides the cost of construction.
- The staging which is a temporary structure to support superstructure construction should be design and checked for different scenario and constructed. Besides the sequence of removal of staging to be defined to avoid any structural damage of bridge girder and deck.

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Conflict of Interest: The author declares no conflict of Interest.

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Revitalization of Fire Safety Approaches in Traditional Buildings of Bhutan through Material Discontinuity and Water Mist Sprinkler System

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Abstract: The native architecture style of Bhutan has elaborative use of timber fenestrations at all levels of the structure. Dzongs, monasteries, traditional houses and other shelters are often easily built in a Bhutanese architectural style with extensive application of timber. Along with this advantage, an unavoidable risk of fire hazard has become an inherent threat to these structures. This research is an attempt in exploring the suitable approaches in preventing and suppressing the fire hazard in traditional structures. It significantly revitalizes the existing conventional precautions and incorporates suitable interventions like material discontinuity in construction and water mist sprinkler system from relatable cases for a better cause. Material discontinuity involves selection of paints, overhang techniques, preservation methods, separation of ignition areas and redesigning of ignition areas. The interventions are economical and can be applied by public with proper awareness and instruction from relevant agencies.

Keywords: Fire Safety, Timber, Material Discontinuity, Ignition Areas, Water Mist Sprinkler System

Introduction

Fire has been one of the basic inventions of humankind. It came with the necessity to cook food and warm the shelters. However, it can also raze down a structure if it has been mishandled. In Bhutanese context where the construction is predominantly timber, fire control system should be properly placed and installed. On June 24 2012, the 375-year-old *Wangdi Phodrang* Dzong was burnt down to the ground by a fire causing an unavoidable damage and loss to Bhutan in terms of its rich cultural heritage (DDM, 2017). Similarly, fires have destroyed homes and taken human lives in the past. In 2002, 25 traditional houses in *Haa* were razed to the ground while in 2011, two fire incidents razed through *Chamkhar* town causing huge loss and damage to 92 households. So, this research is a rational attempt in exploring the suitable methods in reducing fire hazard in Bhutanese buildings without condemning its core architecture features.

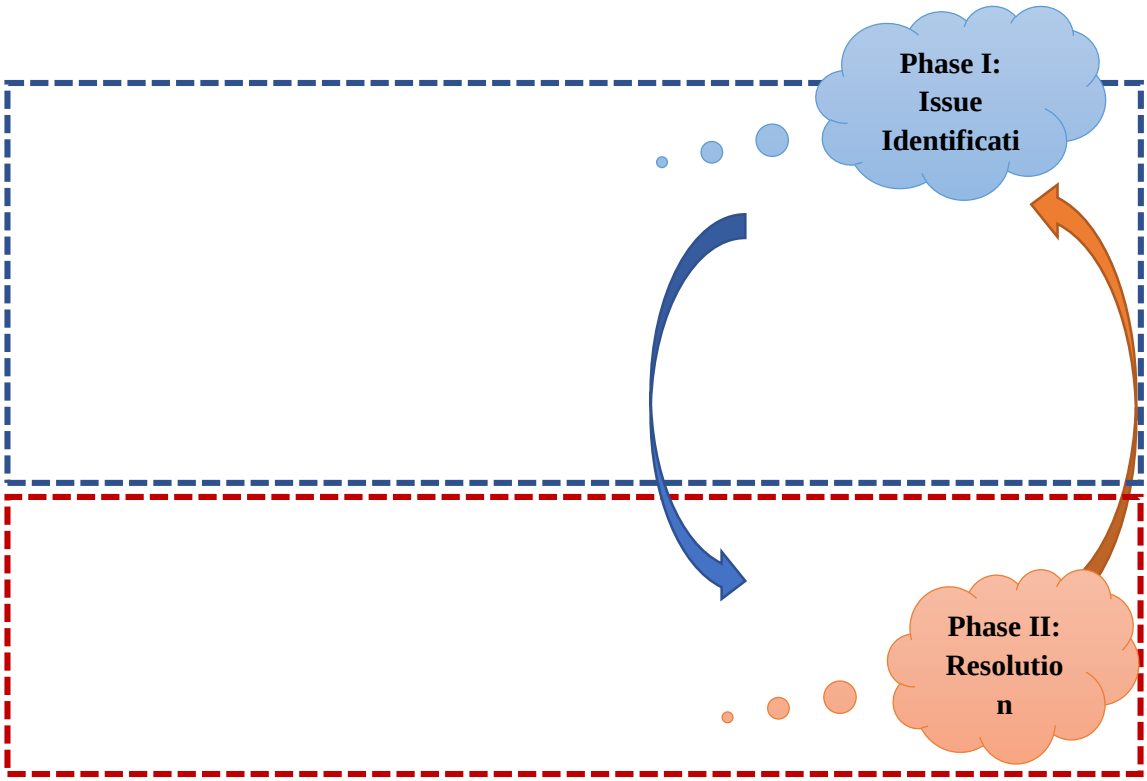
Aim and Objectives

The aim of this research is to revitalize the fire safety approaches in conventional buildings of Bhutan through material discontinuity and a water mist sprinkler system. The matrix of the

objectives is sequentially framed to a cyclic process of issue identification and resolution as shown in the figure 1. Following are the enumerations for the research objectives:

- Explore the existing rules and bylaws of Bhutan relating to fire control system in Bhutanese buildings.
- Exposition of Bhutanese architectural building materials and its combustible properties.
- Identify the impact of different method of fire prevention and control system in Bhutanese architectural building.
- Analyze the functioning of building fire control system in general by conducting suitable case studies.
- Compare study of all the cases and draw suitable inferences.
- Determine suitable approaches from all the case studies to minimize fire hazard.

Methodology



This research is basically a mixture of quality exploration and as well as quantity-based proposition. Its primary means of attempt purely depends upon the relatable cases performed both real-time and online. The research can be phased as a twofold search-procedure. The first phase

includes data accumulation and reviews based on the information available from reliable sources.

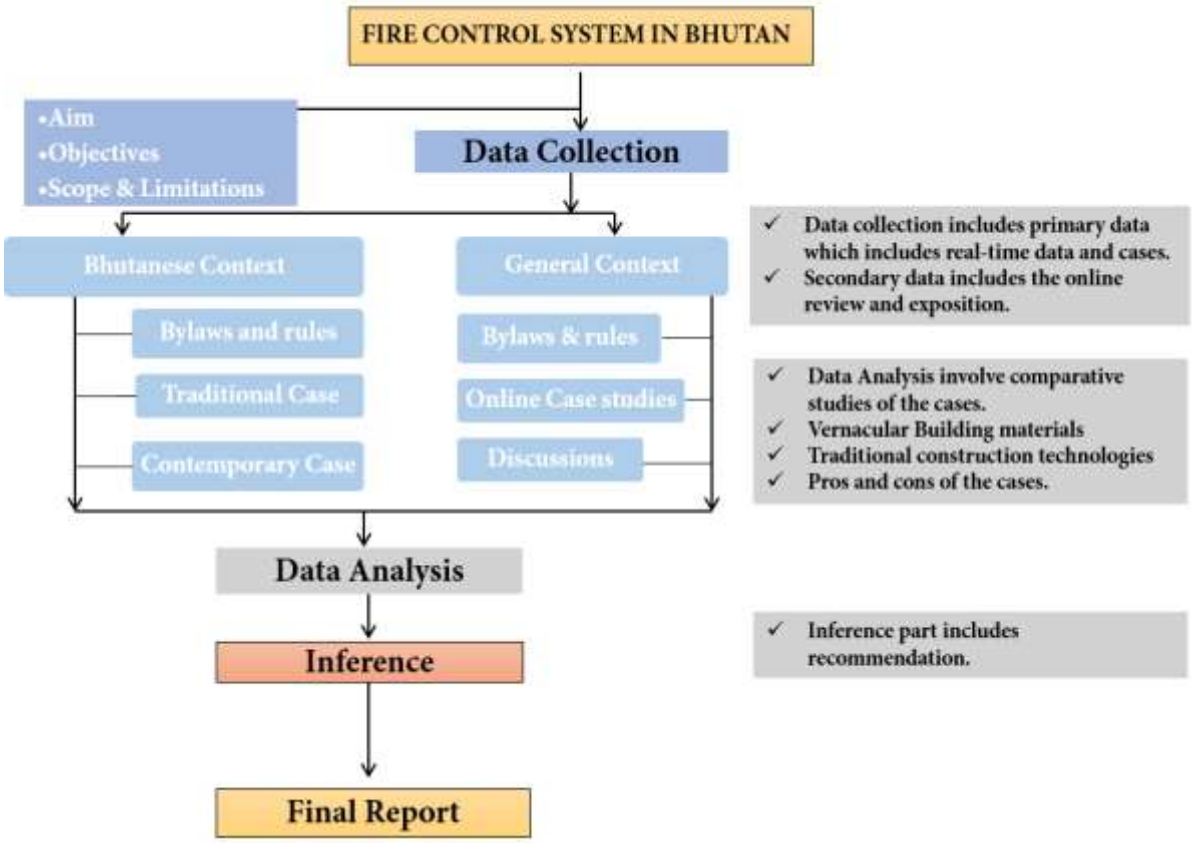


Figure 1. Methodology chart represented as the cyclic realization between twofold phases. Source – Authors

This phase is purely a quality research as it discusses upon the timber characteristics and its intrinsic behavior during the combustion based on modern scientific approach and theories. This phase further explores the standards and regulations at the general level, as well as at national level. This part of the research widely discusses the general understanding about the fire and its safety in buildings.

Data Collection & Analysis

For timber having naturally combustible characteristics to fire, a study undertaken by the Department of Disaster Management (n.d) revealed that building and house fires in Bhutan are largely attributable to inevitable faulty in electrical installations. Potential sources of ignition from electrical installations, insufficient emphasis on prevention and responsibility and lack of application of available fire-protection engineering expertise are some root causes of the fire hazard in buildings (Dargye, 2016). Therefore, the fire detection and control system has become an integral part of building system in Bhutan compared to other building automation system.

Timber as building construction material for traditional buildings

Wood has been a favored material for construction from the starting of human civilization as of its availability, high stiffness and tensile ratios and the proportionate simplicity with which it can be adjusted to use (England, 2016). A quantitative analysis done in a typical traditional building of Bhutan projected that 63.5% of the building mass includes timber along with 35% masonry materials such as stone, mud and etc. The remaining 2.5% includes the finish layer such as plaster and paints along with other material as shown in fig. no. 2 (Volumetric quantification in SketchUp).

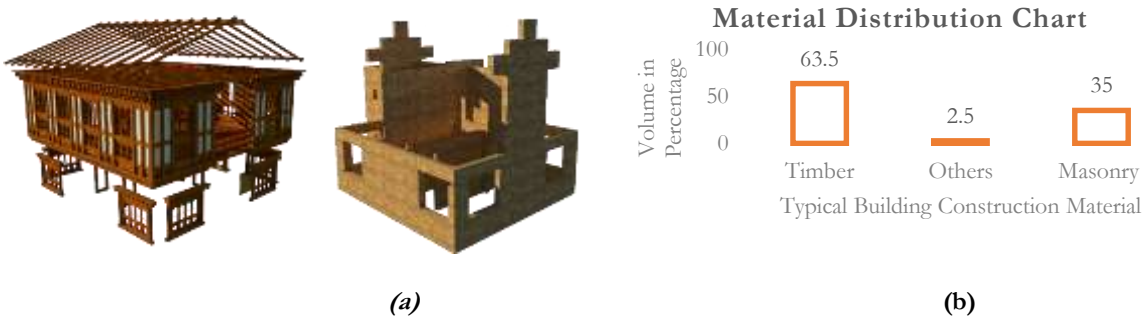


Figure 2. (a)Building Components of the traditional building in Ura. (b)Building material distribution chart.

The construction techniques include timber joineries and vernacular masonry techniques with least intervention of foreign materials and technology (Dujardin, 2006). The timber fenestration shows no discontinuity in their application in most of the first floors and this has been identified as a key cause of fire hazard. As per Bhutan's National Building Code of Bhutan (DHS, 2018), fire safety provisions fall under Part 6 of the guidelines. It has 14 clauses stating the necessary guidelines. It stresses upon the effective human circulation in a building during emergency, escape routes and exits are mandatory for all buildings. Provision of fire escape stair case and design of fire resistance for 30 minutes need to be maintained in institutional and commercial building.

Timber and Fire Safety

Many building regulations and standards strongly restrict the use of timber as a building material (England, 2016) due to its easy combustibility. The existing improvised knowledge in the area of fire design of timber structures, combined with technical measures, especially sprinkler and smoke detection systems, and well-equipped fire services, allow safe use of timber in a wide field of application. As a result, many countries have started to revise fire regulations, thus permitting greater use of timber.

Most structural members require additional fire protection to be applied to provide an adequate level of fire resistance. For example, structural steel normally requires the application of

fire protective boards or coatings and reinforced concrete relies on the concrete cover to protect steel reinforcing bars. Timber members having a large cross-section can achieve fire resistance levels (FRLs) in excess of 60/-/- because when timber is exposed to fire it forms a protective char protecting the inner core of the timber as shown in Figure below. For smaller members this effect is less pronounced and for engineered products such as lightweight floor trusses, I section timber beams, the performance may be dominated by connections or the performance of steel components.

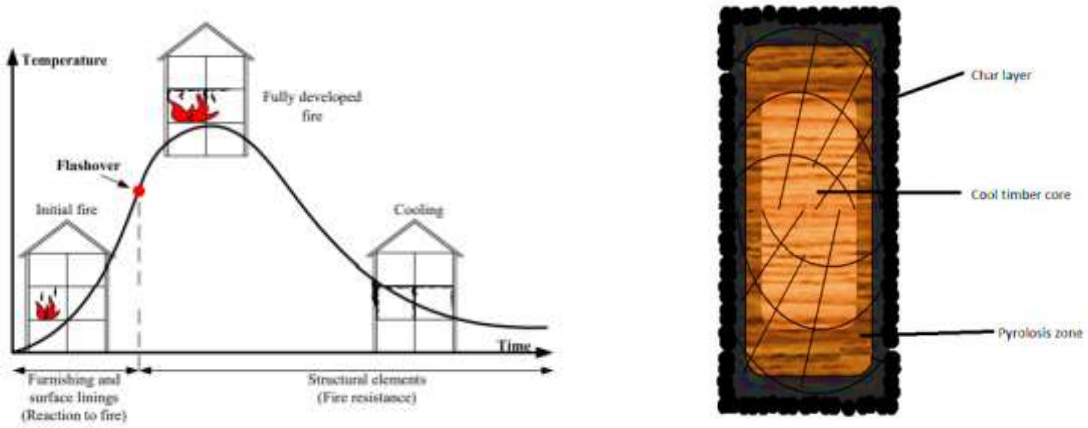


Figure 3. (a) The life cycle process of combustion. (b)Timber-member exposed to fully developed fire. Source – Bing Images

Case Reviews

This research covers a wide range of case studies both online and real time. The study scheme is broken down into two folds: Case studies inside Bhutan and the general case studies outside Bhutan with similar features and problems. The two folds of the case study is mainly framed to firstly explore the contextual features and to expose the general approaches carried out in other parts of the world. To fulfill these two folds case studies inside Bhutan, include a traditional house in Ura and Wangdi Phodrang Dzong while case studies outside Bhutan includes relevant cases from other countries. The following table shows the comparative studies from relatable cases.

Observations

The reviews performed showed that traditional buildings in Bhutan are more vulnerable to fire hazards with short circuit and unmanaged ignition areas as key source of the fire. General limitations have been observed in the NBCB and lack of scientific approach in the construction techniques are again the root cause of fire hazard while public awareness and advocacy on construction techniques are some of the main background causes of the fire hazard.

Table 1. Comparative studies among the cases

Parameters	**Traditional House in Ura**	**Wangdi Phodrang Dzong**	**Mental Health Facility**	**Hedareds Stave Church**	**Residential Building in Khobar**
Location	Ura, Bhutan	Wangdi, Bhutan	New Zealand	Sweden	Saudi Arabia
Building type	Traditional / Residential	Traditional/ Administration	Institutional	Church	Contemporary/Residential
Building materials	Timber, Stone & Mud	Timber, Stone & mud	Concrete & Steel Reinforcement	Timber Exclusive	Concrete, Steel reinforced
Construction technologies	Nail-less, conventional skills	Conventional methods,		Traditional architecture	Contemporary architecture
Probable fire source	Electric discharge, Kitchen fire, Butter lamp	Electric discharge, Butter lamp	Short Circuit	Lamps and short circuit	Ignition areas of the building like Kitchen and short circuiting
Vulnerabilities	Extensive Timber, lack of direct exits, Alignment of Rooms, lack of chimneys	Extensive Timber materials	-	Extensive Timber materials	-
Fire Prevention Measures	General awareness	Proper electrification, management of lamps		Water soluble paints	Escape routes, doors, emergency exits
Fire control system type	Not incorporated	Fire extinguishers, Service tunnel	Recessed Point Type Smoke Detectors	Water Mist Protection System	Water sprinkler system, Fire extinguishers, fire rated doors

Material Discontinuity and Water Sprinkler System

1) Material discontinuity and choice of well-engineered material in the timber fenestrations

The extensive use of timber in traditional buildings in Bhutan is the basic cause of the spread of the fire. Bhutanese architecture incorporates timber fenestrations as embellishment features in the buildings. However, it is least treated against fire hazard. Recent research has shown that it has fire resistant up to certain level, if it is properly seasoned and enclosed with inflammable paints. Proper seasoning and use of thicker timber section in the structure would minimize rapid fire spread in the building.

2) Revitalization of traditional paints as a surface discontinuity

People of Phobjikha use traditional painting over wooden Rabsel which is the trend in the society. The main purpose of using paintings is to enhance the aesthetics of building and to preserve the traditional painting cultures. In one way or other, when buildings of Bhutan which are mainly composed of wooden frames like Rabsel are covered by traditional paintings, it also increased the life span of structure and protects from the fire. The materials used in Bhutanese paint are the natural pigmented soils that are found throughout the country. These natural soil pigments are of different colors and are named accordingly. The black lumps of soil are known as '*sa na'*, and red lumps as '*Tsag sa'*, (Zorig Chusum, 2002). Some area in Bhutan uses lime as paintings to enhance their dwellings and to preserve the wood used in the structures. The limestone and other natural paintings used in Bhutanese architecture acts as a prevention method for outbreak of fire.

(a) **(b)** **(c)**

Figure 4.(a) & (b) Traditional lime paintings at Phobjikha. (c)Overhang technique in Gangtey Goenpa. Picture courtesy Dawa

3) Modern preservation method

With passage of time and development people always go for something which is sophisticated and efficient without considering their impact. There are lot of preservatives that are available in market. Nowadays people always gone for preservative which are produced from industry as is more effective comparing to other traditional method. Although the modern preservatives are expensive, it also enhances aesthetics of structures. Modern building of Bhutan is mainly constructed with wooden Rabsel treated with wood preservative integrated with concrete walls. There are various types of preservatives and it is basically divided into four groups; oil type, solvent type, water soluble (leachable) and water soluble (fixed) (Sedjo, 2012). Some of the most used preservatives are coal tar creosote, coal tar etc. these preservatives are resilient to fire and prevent from the fire.

4) Overhang technique

Every structure of the Bhutanese is loaded with extended over hangs which is considered as traditional architecture for the country. The tradition of adopting extended overhang is inherited from past generation. In hilly region and area where there is maximum rainfall, long overhang is provided to protect the timber. It acts as a method to deflect the direction of rain away from the timber. It also protects the timber fenestration from receiving the direct sunlight. This makes the timber fenestration durable and difficult to catch the fenestration.

5) Separation of ignition areas & redesigning of fire place and butter lamp areas

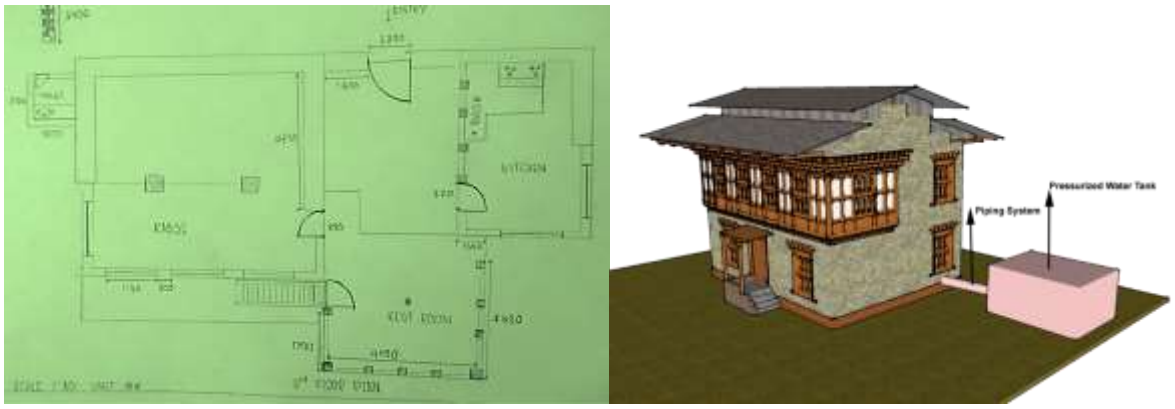
Most of the cases in traditional houses are least developed at the initial stage. The case of Ap Sangay in Ura shows vertically alignment of the ignition areas that is altar on top of the kitchen. The kitchen space is usually an ignition area where heat is generated in enormous amount and if the sparks are ignited fire spread within no time. So, relocation of the ignition areas can be one prevention against rapid fire spread. One fundamental change that can be easily incorporated in alignment of the kitchen is that it should be taken care from the initial stage that it's largely separated from the altar. Another minor change would be to create an open insulation area surrounding the fire-place, 1-meter peripheral protection space should be casted with nominal PCC floor to avoid unnecessary fire spread. The butter-lamp seating base can be substituted with steel plate base or other incombustible material to avoid fire spread.

Methab (fire place) is one of the basic spots for family in the ancient times. The fire place is often built as an open oven area for the family to warm themselves during winter and chimneys are often indicated as a mere hole straight above the oven. This place needs to be separately zoned out from other areas with in-combustible material insulating the main floor area which is exclusively timber material. A separate continuous duct can be a solution. The duct should be made out of highly insulated wall unlike conducting metal pipe which transfer substantial heat within a short span of time. Another realization from eastern Bhutanese architecture where a separate structure for the kitchen can be proposed which is completely separated from the main building.

6) Water-mist Sprinkler system as a suitable fire suppression technology

Occurrence of large timber fenestration and wooden shingles roof on the structure has been always threat to the fire outbreak in Bhutanese houses. During the last few decades, approximately one important and significant structure is raised to the ground by the fire. In the last few years Chamkhar town in Bumthang was destroyed by fire and it imposed huge loss to the people and government. Similarly, there are lots of fire outbreak case in every parts of country. It is mainly

due to lack of prevention system installed in building and moreover the structure is made up of mostly wood which can easily catch by fire.



(a) (b)

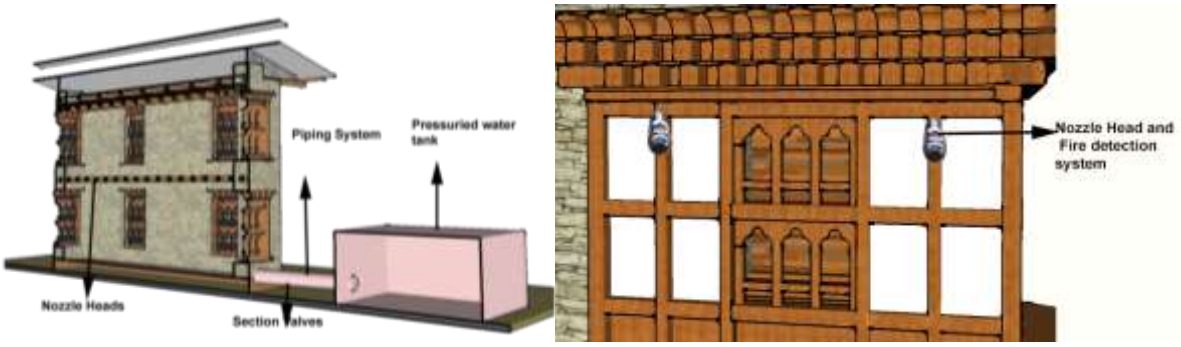
Figure 5. (a)The separation of kitchen space from the main building in eastern Bhutan. (b)Bhutanese house with installed fire suppression system. Illustration and model source authors

Dzongs or other important historic structure should be installed with fire suppression system. Once the structure is destroyed, it is said that the structure cannot be rebuilt same like the original structure. In Sweden some important churches which was destroyed by fire are kept without being touched to keep the authenticity of structure. The churches in Sweden are mostly made up of wood and it has old crucial paintings on the walls like dzongs in Bhutan. Proper fire protection method is applied on structure after considering following recommendation:

- Requires unique and innovative solution
- Low-cost method
- Choose a method which do not have interference with the building
- New installation must be accessible for maintenance and detachable without causing damage
- Technical installation and signboard must be discrete (Arvidsson, 2008).

In the past Bhutan does not installed a fire suppression system in building. With the development people started installing fire protection measures in large building like dzongs and hotels. Bhutan does not adopt much passive fire protection system in buildings. Prior to installment of fire protection system in building, an overall strategy must be prepared. Combination of organizational and technical fire precaution system and a proper organization can reduce the need for technical adaptation. Technical installation for fire protection system includes fire detection system, fire alarm system, lightning protection and video surveillance (Arvidsson, 2008). Unlike other system like sprinkler system which cause damage to the structure, it provides water in the form of mist that cause low damage to the buildings. Other suppression system like

use of gasses is comparatively having cost installment. The figure no. 51 shows the installment of simple fire protection system in Bhutanese house. The high pressurized water is passed from water tank to the building. The water in piping system is pressurized by high pressure pump unit which is passed to nozzle head in specific location. The reduces the size of droplets to 200 to 500μm which is very efficient in reducing the fire. On the other hand, it causes less damage to the structure.



(a) **(b)**

Figure 6. (a)Section showing water mist fire suppression system in traditional Ap Sangay's house. (b)Fire protection of facade of building. Illustration source authors

7) Protection of facades and roof of the structure

For the protection of façade and roof of the building, the Bhutanese house will be installed with the fire detection system which is attached with water mist fire suppression system of the building. The roof and façade will be installed with separate nozzle head for the protection. The façade will be installed with the electric linear heat detector with fixed alarm temperature which is rated as 68c same like churches in Sweden.

8) Awareness and proper electrification

At this time where the education becomes the tool of development and civilization, awareness and beforehand prevention are always plus point to any potential hazards. The indigenous art of constructing houses should evolve without diverting its core values but structuring properly against any hazards. Expertise in multi-areas such as plumbing, electrification and other minor details need to be worked out properly beforehand. Awareness is another tool that can enforce proper construction techniques and fire control system should be made at grounds where everyone can afford and understand the significance.

9) Provision for scientific remote controls

As explained in the case studies part, the suitability relationship of mist sprinkler system and wireless fire protection and control system in traditional timber construction, the combination of these two systems is recommended after suitable and critical analysis of their impact on nature of

timber. The mist sprinkler system reduces the decay impact on wood when sprinkled during hazards and if the structures stand up to further conservation and or use. The installation of traditional fire alarm system (Wired system) requires drilling into the fabric to hide the wiring system that is not pleasingly applicable in traditional Bhutanese architecture especially in conservation and preservation of heritage buildings. The installation without hiding the wire would create other obstructions in its original aesthetics, and users' comfort. Moreover, the thickness of the walls (Ekra walls) in Bhutanese traditional buildings are very thin where the drillings and hiding of wires is impossible. The installation of wireless fire protection and control system avoids this disadvantage making it suitable for installation in traditional buildings.

Conclusion

Fire hazard is one of the dangerous disasters with highest number of loss in both wealth and lives of the country (DDM, 2018). With the recent loss of Wangdue Phodrang Dzong and the massive destruction of Chamkhar town, Bumthang, government have enforced the construction sectors to carefully look into the matter. While this research tries to explore the general exploration of timber as its intrinsic material and then expose its inherent characteristics against fire. The timber in itself is an insulating material with high resistivity value but in long run after its ignition temperature is achieved, its combustion is a rapid process. The country regulations specify no particular guidelines against the construction while a general outline of fire escape measures have been only laid. The latest euro-code for fire, saw specifications of the houses and the categories of wood they have consumed and respectively a code for unique exhibition during construction is generated.

The native architectural style of the country with elaborative use of timber fenestrations is the key cause of the fire hazard with least attention given to the ignition areas design. This research explores the general exploration of timber as its intrinsic material and then expose its inherent characteristics against fire. The timber in itself is an insulating material with high resistivity value but in long run after its ignition temperature is achieved, its combustion is a rapid process. Case studies were performed to deduce significant real time interventions and data from the relatable reviews.

The attempt finds its way forward in fundamentals of timber treatment right after it's been lumbered. It includes the proper process of choice of timber material, the process of seasoning they should undergo and list of procedures in making them more insulating. The organic traditional painting which is widely practiced is considered a novel culture and scientifically it acts as a thin membrane against the external agents. This research realizes it's important and the practice should

be carried extensively. Another intervention emphasizes upon the revitalization of the conventional precautions such as separation and realignment of the ignition zones of the houses. The traditional *methab* or the oven area should be peripherally casted with PCC floor to avoid unnecessary spread of the fire.

One proposal is the application of water mist sprinkler system in traditional homes with a separate control room built near the house. This built-in system is proved effective in the wooden churches of Finland where it acts as the practical fire suppression system during the fire event. Other means of scientific approaches such as multi-sensor application has been covered too. Other inventory includes awareness among the public and recodification of building rules and regulations concerning fire safety in timber buildings. These are some of the possible findings from this attempt.

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Green Infrastructure Planning in Bhutan: A Review of Existing Literature

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Abstract: As the world urbanizes rapidly, humans are increasingly exposed to the effects of urban development. Degradation of ecosystem services like clean air and recreational services caused by the reduction of urban green spaces or its network called the green infrastructure, leading to an eventual decline in human well-being is the main issue in urban areas like Thimphu today. Lack of a system that integrates green infrastructures planning in the mainstream development process, as well as the general perception of users and decision makers alike on the importance of ecosystem services to individuals' and city's well-being are the main causes thereof. At this backdrop, this study is an exposition of two interlinked approaches that serves to respond to the mentioned issues; firstly, how green infrastructure and the ecosystem services that it provides can be assessed for its economic value to exalt and validate its status from being a mere standalone space to a life and economy supporting infrastructure and ensure the prioritization of these spaces in decision making processes. Secondly, how green infrastructure planning as a tool can be used to mainstream the green spaces and its benefits in urban planning and development process for the sustainable future of the urban areas like Thimphu. Furthermore, the study also gives a due heed to the legal and institutional framework in the country to understand the possible areas for integration of the aforesaid approaches in the mainstream urban planning and development process.

Keywords: Green Infrastructure Planning, Ecosystem Services, Valuation

A Brief Introduction on Urban Green Space Issues

Planet Earth has inherited a unique natural characteristic compared to its sister planets. These characteristics, or for that matter, natural environment has been for ages the basis for all forms of life (Daily, et al., 1997). The system wherein living organisms interact with each other and with the non-living components of its environment for energy and nutrients to survive and reproduce is called the ecosystem (United Nations, 1992). Whilst these living and non-living components interact with each other through processes such as nutrient cycles and energy flows, humans receive multitude of benefits through these ecosystem processes, which are also called the ecosystem services (Daily, et al., 1997). At this instance, it is important to understand the status of the inverse relationship that these services share with development, viz., declining ecosystem services and increase in global development. Even more so, this trend is more pronounced in

urban areas that are developing at an exponential rate. Unlike the wide range of natural components and its processes that can be found across the world, in urban areas, the sources of these ecosystem services are limited to urban green spaces network called the green infrastructure, which are decreasing by the day. Likewise, notwithstanding the national contribution and commitments that Bhutan upholds in terms of its rich natural environment, the issues of deteriorating green infrastructure and the ecosystem services that it provides are prevalent in Bhutanese urban landscapes. For instance, Bhutan has more than 70% of its land under forest cover, and as enshrined in the constitution, the forest cover will have to be more than 60% at any point of time in the future. However, the open spaces, riparian corridors that otherwise used to be interspersed with the urban built environment in the olden days are dwindling at a soaring rate. Similarly, albeit the fact that Bhutan has several initiatives, including the Principle of Gross National Happiness that advocate and support the preservation of its environment, the access to green open spaces, or the green infrastructure in its entirety, in the urban areas, are often limited to its peripheries. In fact, the green open space per capita ratio within major urban centers in Bhutan like Thimphu and Phuentsholing is below the global standard of 9 sqm per person recommended by the World Health Organization (World Health Organisation, 2009).

One of the reasons that underlie the said issue is the fact that urban areas such as Thimphu is confronted with several urban challenges, like rapid urban population growth leading to concomitant socio-economic and infrastructure development needs, which stand against the meagre developable urban land. In the context of the said urban challenges, the available green open spaces are often considered as the most appropriated site for such developmental needs and in the process, these spaces are replaced by the more environmentally recalcitrant gray infrastructure. Despite several attempts to abate the issue from the environmental and social fronts, these spaces often give way to a proposal that portrays highest economic benefits. Moreover, the green infrastructure within the city is forgone at the pretext of having the same elsewhere, usually outside the city limits. Therefore, in the light of the aforesaid issue, it is imperative to comprehend and unravel the question:

- Research Question: How are ecosystem services of urban green spaces measured and prioritized as an input to mainstreaming green infrastructure planning in the urban development processes for the well-being of the urban residents?
- Aim and objective: The study intends to disseminate awareness and broaden the perspective on urban green spaces as an important component of an urban area, especially due to the wide range of ecosystem services that they provide, as well as due to the huge economic implication affiliated to the loss thereof. The study also intends to

expend Green infrastructure planning tool to mainstream the preservation of the green infrastructure and its ecosystem benefits in the planning and urban development processes.

- Methodology: Due to the novelty of the study in the country, the study will be mostly based on the review of existing literature, mostly, on cases pertaining to the subject elsewhere in the world. Nonetheless, an essential part of the study, that will bring to light the relevance of the study in the local context of Thimphu, is the study of exiting status of its urban green spaces. Furthermore, in order to bolster the study, inferences from a residents' survey carried out in neighborhoods in Thimphu shall also be expended as a part of the study method. The inferences from the literature survey (presented in the form of two approaches; Economic valuation and green infrastructure planning to highlight their economic, social, and environmental benefits) and the underlying opportunities in country, particularly in urban centres like Thimphu, will be put against the green infrastructure issue to produce recommendations that can be adapted, especially, in the urban planning process for the protection and enhancement thereof. Further, assessing avenues to integrate the said recommendations pertaining to green infrastructure planning in the existing planning process by leveraging the existing legal and institutional framework is another aspect the study will cater to.

Ecosystem Services and Green Infrastructure

The Millennium Ecosystem Assessment (MA), a global initiative, defines ecosystem services as: "the benefits that people obtain from ecosystem". This includes goods, such as timber, and services such as air purification. The MA apportions these services into 4 different yet interlinked categories:

- Provisioning services: Goods provided by the ecosystem like timber, food, etc.
- Regulating services: Benefits received from the ecosystem regulation, such as water purification, air purification, flood control, regulation of climate (carbon sequestration).
- Cultural services: Benefits such as recreation, aesthetics, and mental/personal growth received from the ecosystem.
- Supporting services: Biological processes like soil formation and nutrient cycle necessary for the production of all the other services. (MA, 2005)

In an urban context, despite the fact that urban green spaces are attenuating, one can find different types of green spaces like parks, vacant lands, riparian or river corridors, etc. These urban green spaces are hotspots of various ecosystem services mainly regulating and cultural services.

For example, walkways and playgrounds surrounded by green forests provides cultural services like recreation and beautification, at the same time providing regulating services like air, temperature, and soil regulations. These types of recreational urban green spaces at a wider context of the city offers an opportunity to form a network that constitutes the said urban green spaces also called the hubs connected by corridors such as rivers, creeks, and tree lines and are termed as Green Infrastructure (Schäffler & Swilling, 2012). The presence of green infrastructure (GI) or the network of urban green spaces is vital for urban areas and their ecosystems, as it equips them with the ability to facilitate at all spatial scales the aforesaid ecosystem services that support healthy and secure urban environment for an enhanced well-being of their urban populace.

The Need for a Comprehensive Approach to Green Infrastructure and Ecosystem Services in Urban Areas

Global case: As the world urbanizes, green spaces in the urban areas have declined rapidly, which has instead led to the reduced ecosystem services. For instance, The United Nations Department of Economic and Social Affairs (UN DESA) has mentioned in its report 'the World Urbanization Prospect: the 2014 revision' that 54% of the world's population resided in urban areas in 2014. This was a dramatic increase from 30% of urban population in the 1950s. Further, the report revealed that by 2050 urban population is projected to be 66% of the total global population (UNDESA, 2014). If the current trend of urbanization continues, the urban land cover areas are extrapolated to triple from occupying 0.51% of the total earth's land area in 2010 to increase by nearly 1.2 million km2 by 2030 (Seto, Güneralp, & Hutyra, 2012). Conversely, many of these cities today have less than 10% of its area designated as urban green spaces (World Cities Culture Forum, 2018). These development trends have meant that ecosystem services that green spaces produce especially in the urban areas are severely degraded. The MA report states that in the context of rapid population increase and growing need for food, fiber, fuel, shelter, and fresh water, the world has seen about 60% (16 out of 25) of its ecosystem services being degraded, some even degraded to the point of being irreversible. For instance; By 1960s, the withdrawal of water from rivers and other reservoirs doubled; by 1750, the CO2 concentration in the atmosphere increased by about 32% mainly due to increased use of fossil fuels; and by the year 1980s, 30% of earth's surface was converted into cropland from forest land. Similarly, there has been substantial increase in economic and public health cost associated with damaged ecosystem services, for example, the cost of recovering from damaged ecosystem services like air, and water due to unsustainable agriculture practices in the UK in 1996 was 2.6 billion dollars (MA, 2005).

Local case of Thimphu: In Bhutan, albeit the increase in forest and green areas at the national level, urban areas like the capital city, Thimphu, is confronted with declining green spaces and deteriorating green infrastructure and ecosystem services within its city limits. As per the Population and Housing Census 2017; the urban population of Bhutan has risen from 196,111 persons (30.9%) in 2005 to 274,967 persons (37.8%) in 2017 with Thimphu thromde being the most populous urban area in country with 114551 persons (41.6% of the national urban population) in 2017 as compared to 79200 in 2005 (35.4 % rate of change) (National Statistics Bureau of Bhutan, 2018). With a land area of 21.6 sq.km (which includes the undevelopable/inaccessible areas such as forest, slopes, river buffer, etc.), Thimphu is the densest urban area (44 person per hectare) followed by Phuentsholing (13 person per hectare). In addition, since the preparation of the Thimphu Structure Plan in 2002 and its subsequent local area plans (LAPs), 8 out of 14 LAPs have been implemented with 6 undergoing implementations (Thromde, 2017). Subsequently, the proportion of gray infrastructure has significantly increased (close to 13000 structures in Thimphu Thromde as per the recent geodata survey carried out by the Ministry of Works and Human Settlement in October, 2020). Further, the population growth or the development trends have been observed to be sprawling in the extended areas of the Thromde.

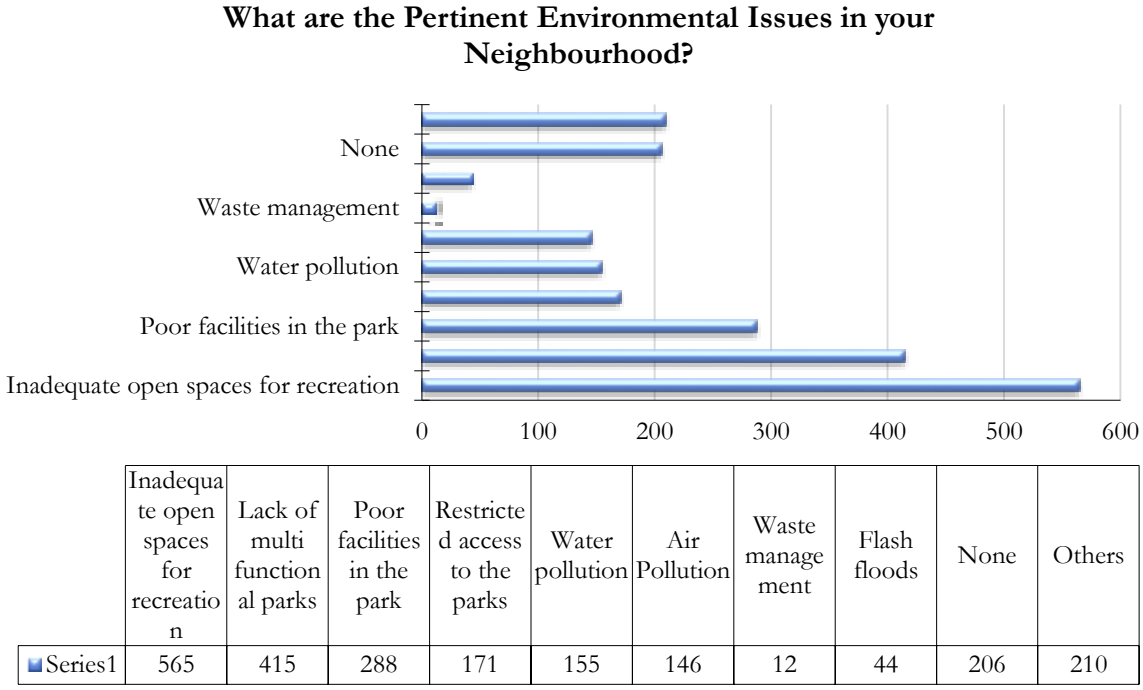
Conversely, the strategic environmental assessment for Thimphu Structure Plan (TSP) carried out in 2017 states that there has been a major land use change pertaining to the green open space precincts. For example; the E-1 or environment conservation precinct (riparian corridors, environmental protection or sensitive area, etc.) decreased from 2.704 sq.km during the preparation of the TSP in 2002 to 1.076 sq.km in 2017, a net change of 60.2%; the E-2 or forest environment areas reduced from 4.359 sq.km in 2002 to 3.953 sq.km (9.3% loss) in 2017; E-3 agricultural environment precinct attenuated from 0.182 sq.km to 0.026 sq.km, which is a staggering loss of 85.7%; the G-1 (National Open Green Space) and the G-2 (Green Space System) precinct, which includes most of the recreational areas such as parks, botanical gardens, sports complex have reduced from 0.726 sq.km to 0.335 sq.km and 0.807 sq.km to 0.552 sq.km, a loss of 53.8% and 31.5% respectively from 2002-2017; and finally the neighborhood nodes which were proposed through the TSP as the center of the 16 urban villages that will provides the required social and environmental services at the neighborhood level have decreased from an area earmarked as 0.2 sq.km in 2002 to 0.081 sq.km in 2017, a decrease of 59.5%. All in all, the green infrastructure areas have decreased from 8.988 sq.km (34.4% of the total thromde area) to a meagre 6.023 sq.km (23%) which is a reduction of 32.9% of all green open space areas in a span of 15 years. (Ministry of Works and Human Settlement, 2018).

The blight of green space reduction can be inferred to many urban issues caused through the reduction of ecosystem services thereof. For instance, due to the increase in the energy consumption coupled with the decrease in green spaces that sequester the CO2 emitted, in 2015, the estimated emission across all the sectors was 2.41 million tons of CO2. The CO2 emission through burgeoning transport sector, which records major increase in vehicle importation and fossil fuel consumption is estimated to grow from 498 kilotons in 2019 to 964 kilotons carbon dioxide equivalent (tCO2e) in 2030. There is an indirect loss to the government due to the rise in pollutants level. This loss can be due to premature deaths, rising health problems, loss of tourism etc. (Ministry of Information and Communications, 2020). Similarly, the soaring rates of non-communicable diseases (NCDs) now account for about 70% of the reported burden of disease. This rising trend is largely due to changes in lifestyle (physical inactivity), dietary habits, among others. NCDs cause the highest proportion of deaths for all age groups and account for 53% of all deaths. Among deaths caused by NCDs, cardiovascular diseases are responsible for the majority of cases (28%), followed by cancer (9%), respiratory diseases (6%) and diabetes (2%). Poor access to green open spaces for both passive and active recreation can be alluded as the main cause. In fact, the National Health Survey in Bhutan found that only 25.5% of the population aged 10-75 years do sports/fitness or recreational activities on the average of 3 days per week and 1.6 hours per day (World Health Organisation, 2015). neighborhood amenities illustrates (refer figure 1) that out of 1264 respondents, 565 (26%) and 415 (19%) thought that inadequate open spaces for recreation and lack of multi-functional parks

A recent survey carried out by the Department of Human Settlement in the neighborhoods of the Thimphu Thromde to elicit residents' perception on respectively as the main environment related issue in their neighborhood. By and large, the greens open spaces and its said ecosystem benefits, in most cases, have been delimited at the outskirts of the city making them less accessible and less affordable due the distance required to travel.

One of many reasons for the degraded ecosystem services and shrinking urban green spaces is the underrepresentation of environmental sector, particularly, the lack of promotion and preservation of urban green spaces in plans and policies as opposed to gray infrastructures. In other words, urban green spaces, more often than not, are being earmarked for the development of other uses like commercial and residential infrastructures. MA asserts that the degradation of the ecosystem services is a direct or indirect effect of changes made to meet growing demands for ecosystem services, in particular, the demand for food, fiber, shelter, and fuels. Mainly because most of resource management decisions are influenced by ecosystem services entering the markets compared to non-marketed benefits that support life. The effect of this short-term bargain is a

long-term implication to the social, environmental and economic aspects of the city. For example, removal of urban green spaces like recreational urban parks leads to the reduction of ecosystem services like recreational services and air purification leading to aggravated health issues, as well as increased pollution level, which in turn leads to a huge monetary, social and environmental implication in the long run (Austin, 2014).



	Inadequate open spaces for recreation	Lack of multi functional parks	Poor facilities in the park	Restricted access to the parks	Water pollution	Air Pollution	Waste management	Flash floods	None	Others
Series1	565	415	288	171	155	146	12	44	206	210

Figure 1. Residents' response on the most pertinent environmental issues in their neighbourhood

Nevertheless, considering recent urbanization issues and the global phenomenon of climate change, urban green spaces have been given equal, if not a higher priority. For this reason, it is a crucial step to understand these spaces as an important ecosystem service provider and adjudge it to be tantamount to gray infrastructure in an urban context. Countries like USA and UK have initiated several studies based on urban green spaces and the wider network of these spaces called the green infrastructure. That said, many cities and municipalities alike in these countries have incorporated green infrastructure in plans and policies. In fact, green infrastructure planning that caters to all the urban green spaces is an indispensable step in preparing the overall master plan of some of these cities. (Lennon, 2013). Green infrastructure planning, on the other hand, is not given its share of priority in the developing countries including Bhutan. Among others, the lack of awareness about its ecosystem service benefits and its value and the subsequent underrepresentation in development plans as stated earlier are main reasons thereof. Therefore, it is of paramount importance that a comprehensive approach that caters to protecting ecosystem services through the management of its sources such as green spaces in the urban areas need to be

in place for a sustainable future of these cities. The ensuing part of the study highlights a combination of two approaches that attempts to respond to the afore-established issue.

Economic Valuation of Ecosystem Services in Decisions (Approach 1: Prioritization)

Apart from the provisioning services like food, fuel, timber, and fibers; ecosystem services that fall under the category of regulating, cultural, and supporting services are not traded in the market, hence, quantification of these services in monetary terms is very difficult. Around the world, due to the stated reason of not having a monetary value, these ecosystem services are not given importance by decision makers often leading to poor tradeoffs that ultimately favors services that have monetary values over those that don't. This is the main reason for degrading trend of ecosystem services around the world (GIZ, 2012). Therefore, it is important to derive a means to assess the economic value of these services. As per the Total Economic value (TEV) Framework (as indicated in table 1), the economic valuation of ecosystem services is done by measuring the use and non-use values of these services. The use values are further broken down into direct, indirect use, and optional values, while the non-use values include the existence values and bequest values. The use values deal with the notion of these services being used and subsequent benefits being gained from the use of these services (food, fuel, etc.), whilst non-use values refer to the satisfaction that comes with the existence of the ecosystems and their services (valuing the existence of pandas without actually seeing one). The common factor in all these methods is the stated preference approach, which delves into understanding peoples' preferences for ecosystem services.

Table 1. Economic Valuation Methods for Ecosystem Services.

Total Economic Value (TEV)					
TEV	**Use Value**			**Non-Use Value**	
Categories	**Direct Use Value**	**Indirect Use Value**	**Option Value**	**Existence Value**	**Bequest Value**
Commonly Used Valuation Methods	Market Based, revealed preference, cost-based and stated preference approaches	Change in productivity, cost-based and stated preference approaches	Change in productivity, cost-based and stated preference approaches	stated preference approaches	stated preference approaches

One of the ways to generate stated preference is through eliciting peoples' perceived values of these services using tools such as willingness to pay or contingent valuation method. Given the importance of economic valuation of ecosystem services, many studies show that countries,

especially in the west, have used the aforesaid use and non-use valuation tools to ascertain their economic values.

Some examples of economic values measured for ecosystem services are as follows; the economic value of cultural services like recreation is high in countries like UK. The cost of sedentary lifestyle is over 12 billion dollars annually. This is attributed to the health implication that results from an inactive life style such as obesity (Grant, 2010). Similarly, in the US, studies have shown the value of public recreational facilities to be around 452 million dollars per year (The Trust for Public Land, 2010). A study has shown that prices of houses increased by 8%, if it had the view of a park, and prices raised by 6% if the house is located adjacent to a park (European Commission, 2012). Globally, preventive measures for pest and diseases in agriculture accounts to 400 billion dollars. 30% of crop production that requires pollination has an economic value that is equivalent to 10% of the world agricultural output (Norris, 2010). The wetlands in USA provided economic benefits of 5,200 dollars per acres pertaining to flood control (Kim, Cho, & Roberts, 2011). The total economic impact of global warming is estimated at 3 to 12 trillion dollars (Thornes, 2011). A mature tree of selected species can absorb as much as 0.5' of rainfall, a cluster of 100 trees can capture about 54900 gallons of rainwater, thereby preventing floods as well as providing fresh water for consumption (Mcpherson, Simpson, Peper, & Xiao, 2011). In Bhutan, the indirect economic loss from increased pollution level is estimated to be Nu 3,220,000/tons for PM emission and Nu 23,800/tons for NOx emission24 (Ministry of Information and Communications, 2020). Similarly, the financial implication of referring and treating the patients with the NCDs, as implied in the earlier part due to poor access to recreational open spaces, have increased significantly from 529 patients and a cost Nu 81 million in 2006-2007 to 1047 patients and Nu 180 million in 2012-2013 (World Health Organisation, 2015). The economic valuation of ecosystem services is an essential step to provide importance or priority to these services in decision making through the illustration of direct or indirect economic benefits received from ecosystem services, as well as economic losses suffered due to degradation of the same (Austin, 2014). GIZ, a German development agency, has stated benefits of generating economic values of these services and imputing them in decision making like:

- Evaluating the impacts of development policies and policy interventions that alter the condition of ecosystems and consequently effects human well-being.
- Comparing the real cost-effectiveness of an investment project; evaluating trade-offs between different ecosystem management options and choosing between competing uses and assessing liability for damage to the environment.

- Creating markets for ecosystem services in order to mobilize financial resources, e.g., global carbon market and payments for ecosystem services.
- Awareness building and communication to the public on the overall contribution of ecosystem services to social and economic well-being (GIZ, 2012).

Green Infrastructure Planning (Approach 2: Deliver ecosystem benefits to residents)

A step that follows the prioritization of the urban green open spaces through deriving its economic value is to plan and manage these spaces. Green infrastructure planning is a strategic planning approach that strives towards developing green space network, especially in the urban area that is designed and managed to deliver a wide range of ecosystem services at all spatial levels (Hansen, Rall, Chapman, Rolf, & Pauleit , 2017). Along with important features of green infrastructure like connectivity, integration, and multi-functionality, the attributes of green infrastructure planning that illustrates its applicability in various scales from a community to regional level and the emphasis on different ecosystem benefits form its main guiding principles (Hansen, Rall, Chapman, Rolf, & Pauleit , 2017). All in all, the core principles of green infrastructure planning can be summarized as:

- Connectivity: It is the strategic connection between the urban green spaces such as parks, riparian corridors, etc. that maintains the unrestrained distribution of the ecosystem services
- Multi-functionality: To combine the ecological, socio-cultural, and economic function of urban green spaces to provide multiple benefits concurrently
- Integration: Physical and functional coordination between urban green spaces and gray infrastructures that provides various benefits simultaneously. For example; trees planted as road buffers can firstly improve aesthetic values of roads, secondly reduce pollutants in the air.
- Social inclusion: It intends to provide an equitable access to urban green spaces and ecosystem services for all (Hansen, Rall, Chapman, Rolf, & Pauleit , 2017).

But, by and large, the most important aspect of green infrastructure planning approach as revealed earlier is the emphasis on the ecosystem service, and for that matter, making informed decisions that support the conservation of these services through management of green infrastructures to eventually promote human well-being. A timely information about the ecosystem service degradation and other findings pertaining to its assessment would provide valuable inputs and impetus to green infrastructure planning. For example; planning for critical green spaces before developing gray infrastructure; supports farm, forest, and landscapes for tourism; using

green infrastructure to mitigate or making the communities disaster resilient are few out of many benefits of green infrastructure planning (Amundsen, Allen, & Hoellen, 2009).

There are many success stories on green infrastructure planning in the USA and UK. For instance, the storm water management success in many local governments in the US such as Chicago-Illinois, Portland-Oregon, among others, through a strategic green infrastructure planning process that entails mapping, public participation, incentivizing to expending regulations and policies, etc. is a commendable example leading unto socio-economic and environmental benefits. (United States Environmental Protection Agency, 2010). Similarly, the report published by the Green Building Council of the United Kingdom, illustrates 18 cases of GI Planning success in various places in the UK, where green infrastructure plans and its projects have led to environmental, economic and social benefits. One example of the case study is the 'The Crown Estate London Ecology Masterplan', which guides the installation of contextually valuable green infrastructure (GI) throughout The Crown Estate's London portfolio. This will provide valuable habitats for wildlife on and around the buildings, and improve the experience for people who live, work and visit the area. (UK Green Building Council, 2015).

Green Infrastructure Planning Process

Green infrastructure planning has become an integral part of spatial planning in many cities across the world. There are several examples pertaining to green infrastructure planning process and the steps involved. But in general, these steps can be summarized into 6+ steps planning process as follows:

Step 1. Set goals: The green infrastructure planning should start with the formulation of goals that not only identifies the urban green spaces and ecosystem services physically and functionally active in the city but also ascertains the natural assets and functions that are valued by their communities.

Step 2. Review data: this step explores and reviews existing data pertaining to urban green spaces and ecosystem services in the city

Step 3. Prepare green Infrastructure maps: In this step, green infrastructure maps are made based on the goals establish and available data. The maps emphasize the conservation and enhancement of urban green spaces and ecosystem services that community values the most.

Step 4. Assess risks: assesses the risk (based on the maps in step 3) on urban green spaces and valuable ecosystem services that they provide. Assessment of the risks such as; which green

spaces are affected or may get affected by current development patterns and processes; which biological corridors and green spaces are impaired, etc., are carried out under this step.

Step 5. Rank the assets and determine opportunities: The valued assets measured in earlier steps are now ranked according to their vulnerability or susceptibility to degradation. And accordingly, these assets are ranked to ascertain, which out of these natural assets and functions need immediate attention and improvement.

Step 6. Implement: Based on findings in earlier steps, policies, plans, and projects are implemented or the existing laws and zoning ordinances are reviewed to ensure the protection and enhancement of prioritized natural assets and functions. Change of land use planning steps; awareness programs and encouraging peoples' participation in plan preparation and other voluntary conservation actions; and data that need to be prepared to monitor urban green spaces in the city are some of the attributes that constitute the step (Firehock, 2015).

Step 6+. Integration of ecosystem service assessment: Ecosystem services assessment represents a holistic thrust for green infrastructure planning process. The six-step GI planning process as mentioned earlier mainly deals with the urban green spaces and the ecosystem services that are existing in the city and are valued by its populace. Despite the emphasis on ecosystem services, the process mainly revolves around green spaces and the study of ecosystem services is limited to just the ones that are highly valued by its populace. As elucidated earlier, there are many services that people and community are not aware of, but plays a vital role in our daily lives and as a matter of fact, these services might need more immediate attention compared to those that are valued by people. In this respect, ecosystem service assessment that includes analysis of the condition of ecosystem services, level of public awareness on ecosystem services, and environmental and economic valuation should be integrated in the current green infrastructure planning process. This is to ensure that a holistic and a well-informed green infrastructure planning process is achieved so that the process is more encompassing and accommodate plans that cater to multitude of ecosystem services and eventually uplifts human well-being.

Legal Framework and Institutional Framework

In many countries, governments enact laws and provide frameworks for the formulation and implementation of policies, plans, and programs that are conducive to sustaining the natural environment and ecosystem services that they provide. Sometimes, these laws take shape in the form of international agreements, whilst mostly, they manifest in the form of national or sub-national laws that dictate ownership, taxation and use of natural resources (Ranganathan, et al., 2008). In Bhutan, under the rubrics of 'Gross national Happiness', there are many environmental

laws such as the; Forest and Nature Conservation Act of Bhutan (1995); Land Act of Bhutan (2007); water Act (2011); National Environmental Protection Act of Bhutan (2007); Environmental Assessment Act (2000); and Biodiversity Act (2003) that regulates and safe guards the natural environment. On the other hand, notwithstanding the lack of robust urban planning laws, there are National Human Settlement Policy (2019); National Human Settlement Strategy (2017); and other rules and frameworks to be more precise, that offer avenues for the integration of environmental preservation or for that matter the green infrastructure processes mentioned in the earlier part of the study in the current urban planning and development processes. Nonetheless, while the existing laws as mentioned before could be a plausible startup-base for assessing the benefits of ecosystem services provided by urban green spaces in cities, together with collaborative efforts of responsible institutions, results of these studies would also rejuvenate the importance given to green spaces as vital ecosystem service provider, so that new laws and policies are formulated and existing policies are reviewed by decision makers to incorporate green infrastructure planning in city's urban development plans and policies.

Conclusion and Recommendations

The study, not only recognizes urban green spaces as a sole provider of ecosystem services in the urban context but also its contribution to the development of the city and the well-being of its populace. The conventional development processes that are degrading ecosystem services and urban green spaces are conspicuous throughout landscape of urban centers like Thimphu, and needs appropriate expedient to control or to quell these trends. The study results ascertain green infrastructure planning as a measure that can address the aforementioned issues. That said, it has been affirmed important that for green infrastructure planning to materialize and potentiate the development processes that conserve urban green spaces and its benefits, it needs to be incorporated firstly as an essential part of the urban planning and development process itself. For instance, creating corridors like center islands, tree lines, buffers, biological corridors, etc. to connect various green infrastructures; construction of roads and houses that integrates with green spaces; assigning multiple functions to urban green spaces by imputing facilities like recreation, nature trails, etc. to increase its functionality; investing and perpetrating awareness programs and activities for the locals and decision makers on ecosystem services, green infrastructure and their importance towards enhancing human well-being; and building city to city green infrastructure network through corridors such as bicycle trails, biological corridors, etc. are some of the practical aspects that represent the study and future green infrastructure planning implementation activities. Nonetheless, on a conclusive note, following are the recommendations from the study:

- Preparation of Green Infrastructure and Ecosystem Service Inventory: All the urban green space hubs and corridors in their entirety be checked and accounted for the kind of ecosystem services that they provide, as well as necessitate a process for a timely check on the condition of these services.
- Assessment of ecosystem services integrated into the development process: Based on the inventories recommended earlier, it is an essential step to assess ecosystem services provided by urban green spaces or green infrastructure in the city and accordingly, identify ecosystem services and urban green spaces that are at high-risk and needs immediate attention
- Integration of Economic Valuation of Ecosystem Service: Assessment of ecosystem services using economic valuation tools be integrated into the planning process to provide urban green spaces a comparable market value and thus importance in the conventional decision-making process.
- Mainstreaming Green Infrastructure Planning: Integrate green infrastructure planning principles, steps and processes in mainstream planning and development process.
- Awareness Programs and People's Participation: The enhancement of people's awareness on the important role of urban green spaces in providing multiple ecosystem services. Furthermore, people's participation in planning these spaces especially in identifying the needs and assessing the importance of urban green spaces and ecosystem services that they provide is recommended for a well-managed green infrastructure network that caters to societal needs.
- Incentives to Promote Green Infrastructure: The local government and other relevant agencies start incentivizing activities that support green infrastructure planning. Rebates to property taxes, development incentives and rights, for properties that have green spaces. Awards and recognition for those activities that supports and enhances urban green spaces and ecosystem services are some examples of incentive to promote green infrastructure.
- Unified GI Planning Plans, Policies, and Programs: A unified green infrastructure plan, policies and guidelines or an institutional framework as a whole that spearheads and supersedes any other policies or local edicts concerning the urban green spaces need to be formulated to encourage a well-coordinated, well-planned and well-managed green infrastructure in the city.
- GI Planning Research: there is a need to expand studies on green infrastructure planning and ecosystem services to provide impetus to mainstreaming green infrastructure

planning in the city's context. Therefore, collaborating with academe such as the Royal University of Bhutan and other such institutions is an important recommendation from the study.

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Highway Slope Stabilization using Soil Nailing Technique: A Case Study of Right Bank Slope at Telegangchu Bridge Construction Project, Trongsa

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Abstract: Soil nailing is a relatively young concept in Bhutan with not many sites in the country using it as a stabilization measure. The landslide in the right bank slope of Telegangchu bridge project is one of the locations where soil nailing along with grouting and shotcrete frame (200mmx200mm) was implemented. Disturbance in the original slope by excavation, increase in gradient and increase in ground water caused the failure of the slope. Conventional methods like Bio-Engineering, stone masonry wall and support of slope base by placement of 9.81 kN sand bags failed to contain the slope. Hence, soil nailing with frame and proper drainage was adopted as the stabilization measure. Feasibility analysis using Benefit, Cost and Speed (BCS) matrix proved soil-nailing with frame to be the most feasible compared to other methods like Bio-engineering, RCC wall and gabion wall. Stabilization by soil-nailing with shotcrete frame proved to be highly effective with drainage playing the vital role in the whole structure's efficiency on implementation at site. This case study and findings paves a way for such strategies to be implemented in similar terrains and soil conditions in Bhutan where conventional methods have failed.

Keywords: Soil-nailing, Shotcrete Frame, Landslide, Ground Water, Drainage, Feasibility

Introduction

Landslide is a very common phenomenon in the Himalayan region, pre-dominantly during the monsoon season (Chaulagai, 2017). "Bhutan" located at the southern foot of Himalayas is no exception to this naturally occurring hazard. "The majority of the national land is mountainous and difference of elevation is large namely 100m in the southern area to 7561m in the northern region", (MoWHS, 2016). Intense rainfall during the monsoon season triggers landslides on this varying range of mountainous terrain disrupting the livelihood and economy of the country. Preventive measures against landslides are often ignored and not given priority. Raut et al. (2018) recommended that from the planning phase itself the steps for avoiding landslides should be initiated. Adopting the most suitable stabilization method is the key aspect to reliability and safety

of any construction. A prevailing trend in Bhutan is the adoption of insufficient slope protection method, which often results in failure of slopes incurring repeated losses to the government.

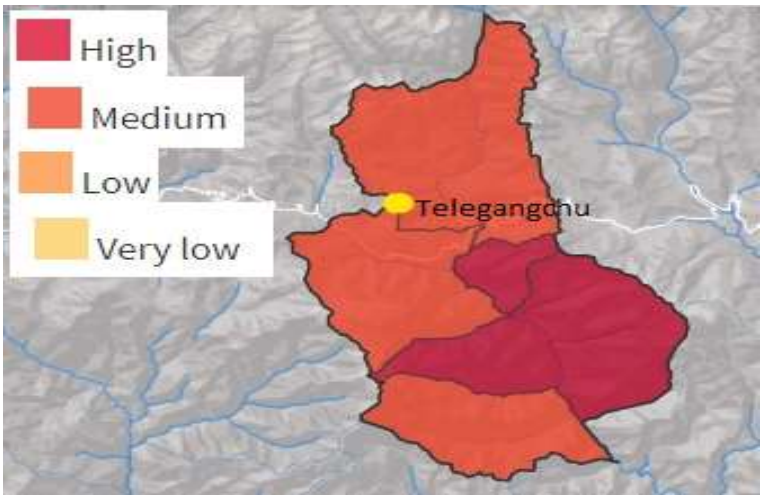


Figure 1. Landslide hazard mapping of Nubi Gewog (Source: ThinkHazard, 2007)

Telegangchu, Trongsa lies in the Nubi Gewog, central part of Bhutan with a population of 3171(NSB, 2017). The location is a Primary National Highway-4 and is one of the most important roads without any alternative route to the Southern region in terms of transportation (MoWHS, 2016). Trongsa Dzongkhag is well-known for road blockages during the monsoon season due to innumerable landslides. In fact, Nubi Gewog is considered to be a medium risk zone in terms of landslide hazard as depicted in Figure 1 (ThinkHazard, 2007). In 2018, a slope of approximately 20m height was excavated during widening of the existing highway for construction of girder bridge project. The right bank slope failed from the center point of 18-meter height from the road level with the onset of summer, 2019. Retaining wall and jute bags filled with 9.81 kN of sand in each were used in an attempt to stabilize the slope temporarily. Due to heavy rainfall and uncertain ground water, the slope was further degraded.

In this context, the paper describes post landslide remedies done in order to gain the stability of the failed slope. In October, 2020 the protection works by use of soil nailing with reinforced shotcrete frame work was adopted to stabilize the critical part of the slope. The main focus of the paper is the methodology of stabilization measure adopted at the right bank slope of Telegangchu Bridge.

Limitation and Scope

The paper is written based on field observation and field tests that were carried out during the investigation period. Practical methodology for construction carried out at site is the focus of the paper. Designer's intention for using certain specifications could not be resolved due to

confidentiality. All the calculations except for the grout and shotcrete mixes have been derived from literature review of research papers and standard code books. The paper provides future scope for studying the post stabilization analysis and implementation at failure sites with similar sub-soil condition.

Location and Geology of the Slide Area

The right slope of the bridge abutment was excavated in a slope angle of 1:1.2 and bio-engineering was initially planned as the stabilization method which will not be discussed in this paper. With the onset of monsoon slight crack 18m above the road level was observed. The first crack was approximately 50 cm which was visually observed by the site engineer. This crack gradually broadened due to continuous precipitation, resulting in a rotational slide. As a temporary measure, tarpaulin sheets were used to cover the crest of the slope failure to prevent further seepage of water into the soil.

(a) **(b)**

Figure 2. (**a**) Aerial view of the slide area (Source: Google Earth); (**b**) Right bank slope after initial slide

Soil investigation revealed that the slope consisted of colluvium mass which was water laden and saturated (Kalachakra Consultancy, 2020). From the un-disturbed soil sample inspection and SPT test conducted, it was concluded that at an elevation of 2116.606m two layers of material were present: 1)up to 9m a saturated layer of colluvium sediments was identified as the main layer causing the slide, 2) Below 9m apart of the bedded strata was found (Kalachakra Consultancy, 2020). Another boring was done 12m below the first boring hole. Same tests were conducted upon it, thicker colluvium sediments were found and two types of slope material were found: 1) of the recent slide and 2) of an older landslide whose cause could not be traced due to lack of data on the matter (Kalachakra Consultancy, 2020). The presence of older landslide material clearly shows that the slope was a dormant slide area. It was triggered by disturbance caused due to excavation resulting in increase in gradient as shown in Table 1, colluvium material with low

bonding capacity present throughout the sliding slope and seepage of ground water at various points at the slide area.

The specific gravity, natural moisture content and wet unit weight of soil condition obtained from the site investigation by Kalachakra consultancy (a sub-contact by the design consultant to carry out the sub-soil investigation), was used to calculate the percentage of saturation and required gradient of the slope. The required gradient was then compared to the provided gradient by excavation in order to determine the stability of the slope as tabulated Table 1.

Table 2. Comparison of required gradient with the gradient provided at site

Soil Sample No.	**G**	**NMC (%)**	**Y_t (KN/m³)**	**E**	**S (%)**	**i_r**	**i_p**	**Remarks**
B-1 (Upper Portion, 1- 2m) UDS)	2.04	19.18	15.892	0.501	78.14	0.693	0.833	$i_p > i_r$, Slope is Unstable
B-1 (Upper portion, 3-4m) UDS)	2.26	15.69	15.99	0.605	58.62	0.785	0.833	$i_p > i_r$, Slope is Unstable
B-2(Lower portion, 2-3m) UDS)	2.18	23.38	15.598	0.692	73.67	0.697	0.833	$i_p > i_r$, Slope is Unstable
B-2(Lower portion,3-4m) UDS)	2.16	19.23	15.794	0.6	69.24	0.725	0.833	$i_p > i_r$, Slope is Unstable

Where, G- Specific Gravity of Soil, $\boldsymbol{Y_t}$–Wet Unit weight of soil, **e**- Void ratio, **S** = Percentage of Saturation, ir- required gradient, $\mathbf{i_p}$– provided gradient, **NMC**– Natural Moisture Content in terms of weight. At all the test points, it was seen that the provided slope was more than the required slope, hence the slope failed.

Stabilization Measures

As of September 2020, the whole landslide was a marshy area due to discreet water sources originating from every part of the slope randomly. The colluvium deposits carried to the road side plains spread in a fan shape clearly depicting silty sand (SM) soil type. Manual as well as excavation using backhoe was carried out to remove all the loose deposits and to prevent further wash away, wooden catch basin and water diversion work was done (as depicted in Figure 3).

(a) **(b)**

Figure 3. (**a**)Fan-Shaped colluviums material deposit at the base of the slope; (**b**) Water diversion using wooden catch basin

Construction facing

Construction facing which consists of wire mesh and shotcrete improves flexibility and provides better air-entrainment for improved freeze thaw protection (Federal highway Administration, 1998). To protect and support the freshly excavated soil, welded wire mesh at an overlap of 100 mm with shotcrete spray of 100mm thickness was provided. The construction facing was not accounted to give structural capacity for frame structure-the final facing.

Soil Nailing and Grouting

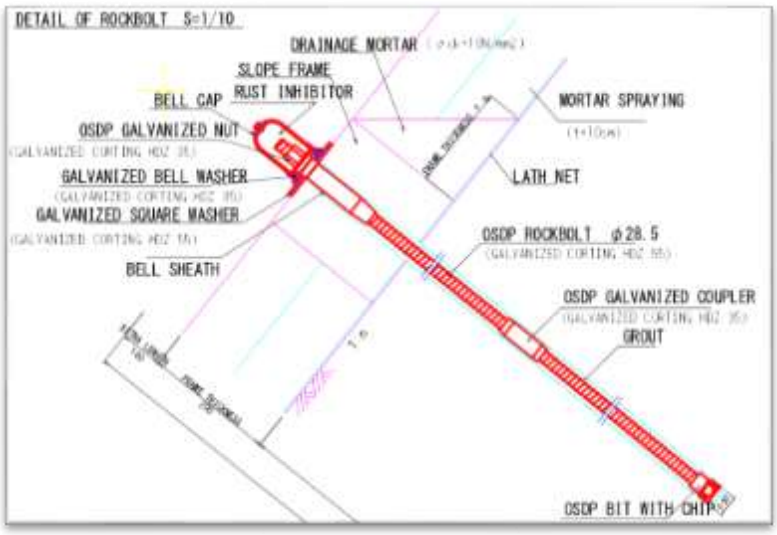


Figure 4. Detail of Soil Nailing Component

Soil nailing is seen to be increasingly adopted stabilization measure on the slopes, especially in hydropower project sites in Bhutan. Soil nailing technique has been used in range of ground conditions from soil to rocks (Galvao et al., 2010). Slope frame coupled with grouted soil nails tend to bind the slope slip surface with the inner resisting zone having higher shear resistance and thereby, reduce the chance of potential soil slip.

A total of 167 number of soil nails along the main slope failure was installed. The length of the nails was 4m with Ø28.5 mm but an initial hole of Ø50mmwas drilled with the help of drilling rig machine perpendicular to the slope face. The nails were drilled at a spacing of 1.5m x 1.5m, as the minimum distance between nails of general gravitational soil nailing is 1.5m (Seo et al., 2014). After drilling, rubber bell sheath 200mm long was fitted from the head of the nail for protection against rusting of the nail and as a base support for square washer which was to be placed at the head of the rubber sheath. Bell washer and nut were fitted on top of the square washer and a bell cap with rust inhibitor was hand tightened as shown in Figure 4.

According to an experimental study conducted by Mittal (2006), he obtained the following relationship between Length of the soil nail (L) and vertical height of the slope:

L/H=0.8, the most critical slope of the slide had a slope length of 7.7 m and vertical height (H) of 4.5m

L/4.5=0.8, L=3.6m. Therefore, a nail of 4m length seems most appropriate for use.

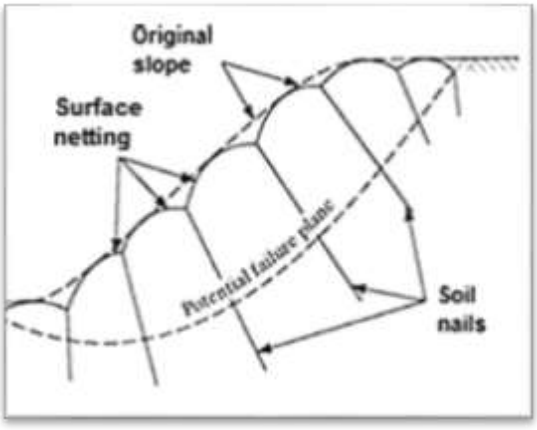
On a 7.7m slope length, 5 nails were driven at an interval of 1.5m Seo et.al. (2014) in their paper provided:

Number of nails (N) $\leq L/S_{min} \times H_{Excavation}/S_{min}$,

Therefore, $N \leq 4/1.5x3/1.5 = 5.3$

Where, L- Length of Soil Nail,

S_{min}- Minimum distance between nails, $H_{Excavation}$- Depth of excavation



Hence, 5 numbers of nails on a slope length of 7.7m were adequate. Soil nails along with surface protection stitches the sliding surface to the stable stratum below and provides stability to the slope as shown in the Figure 5.

In high rainfall area, nails grouted with cement concrete are more effective than just driven nails (Mittal S., 2006). The grout enhances the shear resistance of nails and also seeps inside soil cracks and solidifies which in turn provides greater stability to the soil. The technique was adopted at site as well. Grouting was done after the drilling and insertion of the soil nail to slope by gravitational method. A grout (Refer Table 2) consisting of water to cement ratio of 50% was used (mix ratio for $1m^3$: C=1230kg, W=615L & Admixture=24.6L).

Figure 5. ***Concept of soil nailing (Koerner, 1984)***

Table 2. Grout Mix ratio used for grouting the rock bolt (Soil Nail) is as given below

Design Strength (N/mm2)	W/C (%)	W (l/batch)	C (kg/batch)	Water Reducer (ml/batch)	Mix volume/batch (m3)	Flow (Sec)	28 days compressive Strength achieved (N/mm2)
24	50	25	50	1000	0.041	10~18 sec	31.92

As per the design, the strength of grout to be used was 24 N/mm^2 but the strength of grout achieved at site was 31.92 N/mm^2**.** Hence, the grout strength is enough to enhance the shear resistance of the soil nails.

Final Wall Facing

Final wall facing is provided as a counter weight to the earth pressure that the soil mass exerts due to lateral deformation of the soil. The facing is supported by anchors and metal frames which divides the soil mass into compartments limiting the failure(if any) to just the compartment i.e.1.5mx1.5 m in this case as shown in Figure 5.Frame work of size 200mm X 200mm at a spacing 1.5m x 1.5m c/c was adopted as shown in Figure 6. (a). Four main reinforcement bars of 16mm diameter were provided inside the frame along with 20mm diameter, 750 mm long main Anchor and Auxiliary Anchor of 12mm diameter, 400mm length. A total length of 1492.5m horizontal and vertical frame was provided to cover the active slide slope. Mortar spraying (refer Table 3. For mix ratio) was done to construct the frame and construction facing of the slope as shown in Figure 6. (b).

As per the design, the strength of mortar spray to be used was 21 N/mm^2 but the strength achieved at site was 28.39 N/mm^2**.** Hence, mortar spray mix ratio used for facing works is enough to hold the punching shear stress

Table 3. Mortar spray mix ratio used for frame spray and construction facing is given below.

Design Strength (N/mm2)	W/C (%)	W (l/batch)	C (kg/batch)	Sand (kg/batch)	Mix volume/batch (m3)	28 days compressive Strength achieved (N/mm2)
21	50	22.5	50	150	0.127	28.39

(a) **(b)**

Figure 6. (**a**) Installation of Rebar and Anchors; (**b**) Mortar spray of the slope frame

Drainage

One critical landslide preventive measure in tropical region is to examine the area for potential surface and subsurface water risk. In almost all the slope protection techniques applied around the globe, high importance is given to drainage system. An indirect remedial measure recommended is to provide adequate drainage system, both surface and sub surficial (IS 14680: Landslide Control- Guidelines). One major cause of slide identified through the soil investigation carried out at site was presence of surface and subsurface water causing up to 78% saturation of the soil as portrayed in Table 1.

As a remedial measure, total of 452 numbers of 3m long perforated pipes were inserted inside the predrilled hole of 1.5 m x 1.5 m concrete frame covering the whole slope of the frame structure to improve the natural drainage system of the slope (refer Figure 7. (a)). This helped in reducing the uplift pore pressure. An average of 1.7 m width was covered with 10cm shotcrete above the crest of the slope to further prevent penetration of any precipitation. Peripheral drainage gutter of 300mm x 300mm was provided to collect the surface water and divert it away from the slope as shown in Figure7. (b).

(a) **(b)**

Figure 7. (**a**) Drilling being done for installation of subsurface drainage; (**b**) Completion of installation of drain pipes for subsurface, periphery drainage gutter and completion of shotcrete work

Comparative Analysis

Benefit-Cost analysis is a method used to select the best alternative from a number of available options to execute a project based on the investments and the benefits obtained over time (Vickrey, 1973). In this paper since the return on investment in terms of monetary value over time is not viable i) benefit in terms of durability, feasibility, aesthetic and safety, ii) initial investment as cost and iii) speed at which the project could be completed were taken into consideration for analysis. Weight-ages were assigned to each of the criteria according to their importance for the execution of the project and the ranking for each option was calculated to deduce the most feasible option as tabulated in Table 4.

Table 4. Comparative analysis based on BCS Matrix.

Alternatives	Benefit (70%)					(10%)	(20%)	Score	Rank
	Durability (5)	Feasibility (5)	Aesthetic (5)	Safety (5)	Benefit average	Cost (5)	Speed (5)		
RCC wall	4	4	4	3	3.75	3	2	67%	2
Gabion wall	2	2	2	2	2	4	4	52%	3
Bio-Engineering	1	1	4	1	1.75	5	4	51%	4
Soil nailing	5	5	5	4	4.75	1	2	77%	1

The rating is done in 1 to 5 scales, "5" as the most favorable and "1" as the least favorable to the particular stabilization method against the factors considered to be vital for slope stabilization. The ratings are given based on the approximate calculative designs and a survey from 50 people of different occupation from Nubi Geog. 70% weight age is given to the benefits as it

incorporates the vital factors for any slope stabilization. The speed of implementation given 20% weightage as timely completion was important for economic viability and for minimizing the traffic disruption. From the comparison, it was deduced that soil nailing was the most favorable methodology for stabilization under the conditions given in the problem statement.

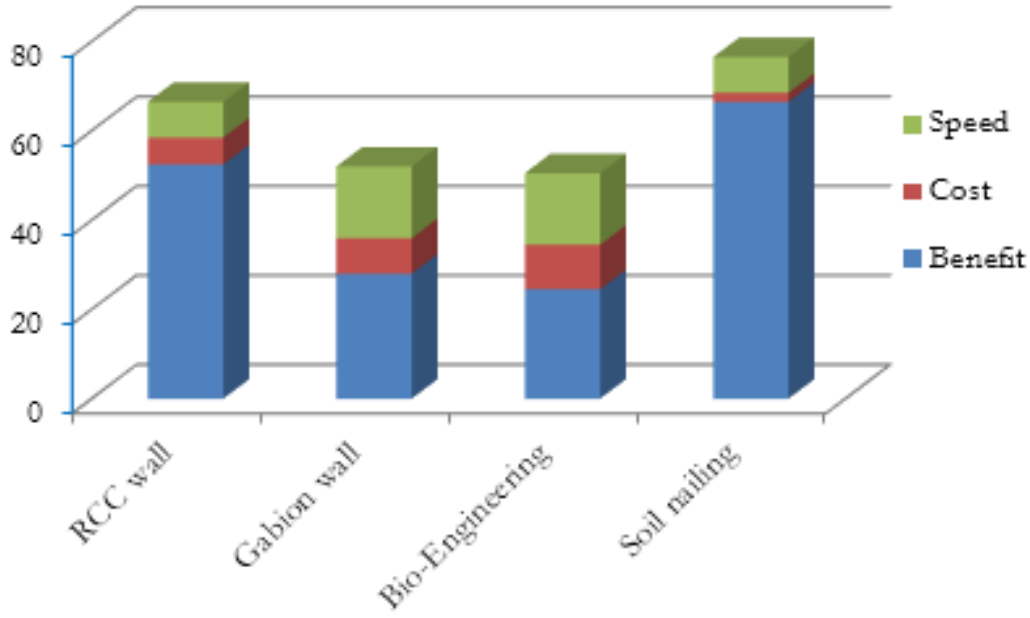


Figure 8. Graph showing comparison between stabilization methods using BCS Matrix

Recommendations

The following recommendations have been made for stabilization measure of a landslide caused due to ground water and unstable soil conditions:

1) Gradient of a slope plays a very important factor in the stability of slope. Therefore, it is necessary to first take in account the type of underlying soil, their saturation level fixing the slope gradient. If the underlying soil is as weak as it was in this failed slope, even a small disturbance can lead to increase in failure slip of a slope.
2) Drainage is hardly given importance though it is one of the key aspects to stability of soil. Ground water weakens the cohesion of soil grains and ultimately leads to shear failure of soil mass. Understanding the sub-surface water condition and channeling it properly as well as surface protection and drainage is vital in any kind of slope protection work.
3) Field tests and sub-soil investigations are very important prior to any earthwork on slope. Many a times, sub-soil investigations are given less priority at the initial planning phase of the project. The result is: annual restoration work and ultimately a huge expenditure in the long run. A mitigation measure based on sub-soil investigation should be

encouraged to curb recurrent restoration and also to minimize the risk to road users, infrastructure and environment.

Conclusion

The Telegangchu right bank slope failed during monsoon of 2019. A thorough geotechnical study was carried out to determine the actual physical parameters of the soil. The main sliding layer was found to be the colluvium soil with high percentage of saturation. A comparison was carried out between the gradient of excavated slope (provided) and required gradient. It was found that the slope was unstable at all points from which test sample was taken as mentioned in Table 1. Accordingly, importance was given to strengthening the structural aspect of the soil.

Soil nailing with grouting and shotcrete was adopted as the stabilization measure with drainage as the key feature. With the method in use, ground water was successfully channelized and the slope visually looks more stable and safer. Using BCS matrix, it was deduced that in comparison to other methods of stabilization, soil nailing with shotcrete frame was the most technically viable solution despite its higher cost. This stabilization method proved to be more beneficial in terms of aesthetic, durability. The method is analyzed as the safest and the most pragmatic solution for slope failure under similar sub-soil condition and terrain.

Acknowledgement

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Conflict of Interest: The authors declare no conflict of interest.

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Study on Riverbed Sediments as Road Construction Material: GSB and WMM

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Abstract: Pavement or road surface is a durable surface material laid on the prepared layers to sustain traffic load. It is composed of different types of layers which influence durability. These layers are termed as sub-base and base course which function as structural components and also act as drainage layers called Granular Sub-Base (GSB) and Wet Mix Macadam (WMM). The study introduces Toorsa riverbed sediment deposits as road construction materials commonly stipulated in Bhutan standard as GSB, WMM and embankment materials. The study aims to provide an experimental and technical investigation to assess its suitability and economic benefit as road construction materials. The variability of the aggregate sizes for natural aggregates is uncertain and variations gap in sizes are expected to be large. As per standard, close graded 75 mm and 53 mm down gauge aggregates are utilized for GSB and WMM respectively. The experimental investigation is carried out to ascertain the quality and corresponding Job Mix Formula (JMF) for particular trials are illustrated.

Keywords: Sediments, Granular Sub-Base, Wet Mix Macadam, Job Mix Formula

Introduction

Road base is defined as a layer of bound materials to give structural integrity to a pavement. In the current study, experimental tests are conducted for recommended structural layers sub-base and base course used in Bhutan. The construction materials used for these two bases are mainly coarse and fine aggregates. Initially, assessment is carried out to verify the quality of the materials with the threshold values suggested by the IS code and the Job Mix Formula are deduced through quantitative analysis by proportioning the mix as per the grading requirements and the resulting outcomes are recommended through this study. Tests in terms of physical characteristics are performed which include specific gravity, moisture content, grain size distribution (IS: 2386-Part 3, 1963; IS:2720-Part 4, 1985), and mechanical properties (IS : 2366-Part 4, 2002): Impact and abrasion values. In addition, during the execution, compaction and water content becomes paramount parameters for proper densification of the sub-base and the base course and hence compaction behavior of the structural materials is studied and discussed. This plays an important role in determining the functional and structural durability of the pavement.

Flexible pavement is the most common type of road in Bhutan owing to geographical settings and topographical conditions. The primary means of transportation in the country is mainly by transport networks to support strategies for socio-economic development. As of 2019, the road network consists of about 18,362.69 km, comprising 15.29% of primary and secondary national highways (MOWHS, 2017) which serves as the back born for the transport network. Flexible pavement is composed of a three-layer structure- subgrade, unbound and bound layer (Sarkar and Dawson, 2017; IRC, 2018; DES, 2020). The unbound layer is commonly known as the subbase or base course layer usually comprises a GSB or WMM just above the subgrade layer in which materials are held together by physical interlock and suction through compaction and water content. A pavement layer is structurally stable if it can distribute the stresses due to wheel load per unit area of the depth of the layer by keeping the elastic deformation within the permissible limits (Math et al., 2016). Hence, it is likely that the pavement sustains a large number of cyclic loading during the design period. GSB and WMM are the main components of pavement, hence, there is a need for stable and non-yielding pavement structures to sustaining the traffic load and optimize the usage of materials for economic construction (Math et al., 2016). Also, one of the most essential functions of the GSB and WMM layers is to provide adequate drainage to achieve longer durability of the pavement (Schaefer et al., 2008). For proper drainage, the layers should have sufficient permeability which allows the flow of water through them. The grading characteristics enhance the permeability characteristics of effective drainage layers and keep the subgrade dry. To achieve these factors, a various laboratory tests was conducted in accordance to IS code to ensure the quality.

Materials and Method

In this study, the samples of natural aggregates sizes approximately ranging from 100mm to 4.75 mm are collected from Toorsa riverbed sediment deposit which extends ~5 km between Phuentsholing town towards Amochhu bridge as shown in Figure 1. The sampling was done from three locations between the mentioned stretch.

The construction aggregates in Bhutan originate from different sources in the regions from a natural quarry, mining and river bed materials. Natural resources such as stone boulders and sand are largely consumed in the construction industry. In Phuentsholing alone, the consumption of stone boulder and sand is as high as 90,000 cu.m and 75,000 cu.m per year respectively (Figure 2). Boulders are commonly used for the production of crushed aggregates of various sizes or are directly used in construction sites.

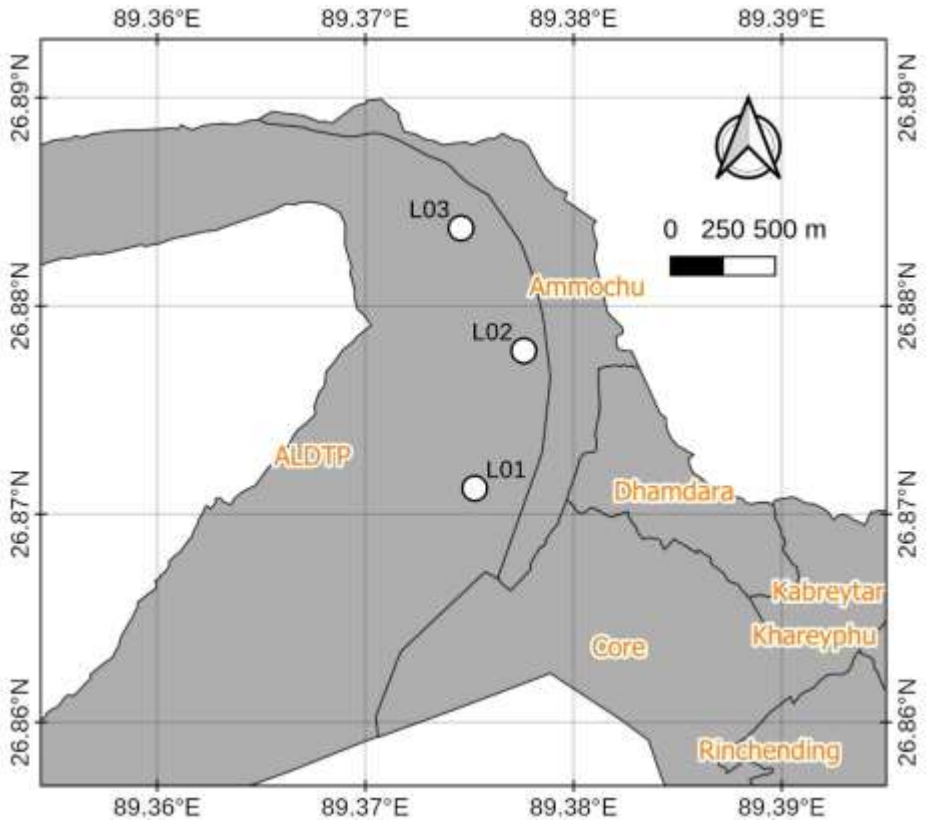

Figure 1. Location of samples at extraction point approved by NRDCL under Phuentsholing Thromde

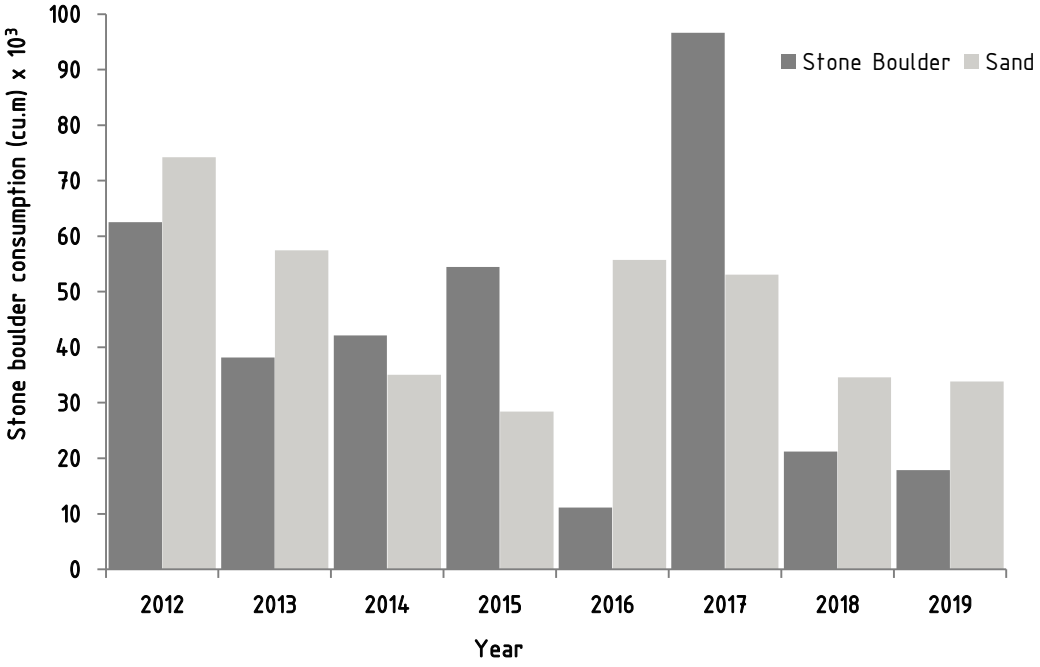

Figure 2. Annual stone boulder and sand consumption from Toorsa river bed (http://nrdcl.bt/)

In the current study, an experimental investigation was conducted to primarily determine the index, physical and mechanical properties of Toorsa riverbed sediment. The quality of these materials when used as a construction material requires qualification to standard requirements set

by the standards. Table 1 presents the summary of laboratory tests conducted in the current study according to IS codes.

Table 1. Summary of laboratory test conducted for GSB and WMM materials

Test	Description	References
Sieve analysis	Determines the particle size distribution in a sample and defines the grading characteristic.	IS:2720 (Part 4) - 1985
Impact	Aggregate Impact Value (AIV) of aggregates provides a relative measure of the resistance of an aggregate to sudden shock or impact.	IS: 2386 (Part 4) - 1963
Abrasion	Los Angeles abrasion test is usually conducted to find the toughness and the abrasion character of the paver block, by subjecting the sample paver block to impact, abrasion, rotating and grinding in the steel rotating drum with 6 numbers of spherical weight balls.	IS: 2386: (Part 4) - 1963
Shape	Flakiness Index of aggregate is the percentage by weight of aggregate particles whose least dimension is less than 0.6 of their mean dimensions. The elongation index test of an aggregate is the percentage by weight of particles whose greatest dimensions are greater than 1.8 times their mean dimensions. These tests apply to aggregates having a size larger than 6.3mm.	IS 2386: (Part 1) - 1963
Water absorption	The molded samples are soaked in water for 24 hours and dried in an oven and air-dried for another 24 hours. In both cases, the water absorption is determined. The percentage difference in weights to the dry weight is water absorption.	IS: 15658 - 2006
Specific gravity	The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of water at the stated temperature.	IS: 2386 (Part 3) – 1963
Modified proctor	The measure of dry density corresponding water content at different loading conditions	IS: 2720 (Part 8) - 1983

Results and Discussion

Quality Assessment

For any construction works, quality control measures and assurance are a must and it plays a vital role in maintaining the durability of the built system. Surface side drains and sub-surface drainage greatly help in enhancing the durability and functional integrity of the road network system. Most commonly, due to poor drainage systems, the development of multiple surface

distresses are rapid that deteriorate the serviceability condition of the pavement (Jayakumar and Soon, 2015; Din et al., 2019).

GSB and WMM not only act as an integral part of the pavement structure but also facilitate proper sub-surface drainage. However, if the gradation of any of these components is not properly maintained as per the specification, the life span of the pavement sustains only a single monsoon. Gradation indirectly plays important role in reducing pavement distresses and subsequent rutting (Chilukwa & Lungu, 2019). Figure 3 is a typical example of pavement failure in Bhutanese roads with a poor composition of sub-base or base materials laid for the pavement.

Figure 3. Post condition of pavement surface due to poor base materials

Specifications for Building and Road Works (DES, 2020) offers a wide variety of materials to be used for GSB and WMM. Some of these materials mentioned are natural sand, moorum, gravel, crushed stone, or a combination thereof depending upon the grading required. Further, materials like crushed slag crushed concrete, brick metal and kankar pointed out which may be used with the specific approval of the Engineer. However, those materials shall be free from organic or other deleterious constituents and conform to one of the three gradings (DES, 2020). Commonly, crushed aggregates from crusher plants, river bed aggregates and natural aggregates are also used in Bhutan. To this end, to assess and assure the quality used for GSB and WMM, various laboratory tests are conducted in the current study for Toorsa reverbed sediment to be used as road construction material. Tests for mechanical properties of the coarse aggregates such as impact value and abrasion tests are conducted to measure the hardness, toughness, and resistance to wear and tear respectively. The test procedure for all these tests conforms to (IS : 2366-Part 4, 2002). The shape test is conducted according to (IS : 2386-Part I, 1963). The shape factor defined in this paper is a combined index of flakiness and elongation indices. The permissible limits for the properties as per (DES, 2020) are presented in Table 2 and Figure 4.

Table 2. Specifications and quality index for GSB and WMM materials

Sample ID	Impact value (%)	Abrasion value (%)	Shape factor (%)	Water absorption value (%)	Specific gravity
S-1	18.2	22.4	25.26	0.13	2.76
S-2	23.1	20.5	24.3	1.42	2.78
S-3	17.8	28.2	23.45	0.98	2.69
S-4	25.2	33.2	20.62	1.56	2.74
S-5	26.7	18.7	25.78	1.78	2.68
S-6	16.85	26.3	19.66	0.24	2.57
S-7	21.45	34	21.5	0.65	2.68
S-8	26.4	16	18.57	1.52	2.58
S-9	27.6	16.2	25.5	1.43	2.66
S-10	21.2	21.5	20.85	1.36	2.53
Max. values (%)	30	30	40	2	2.5-2.8

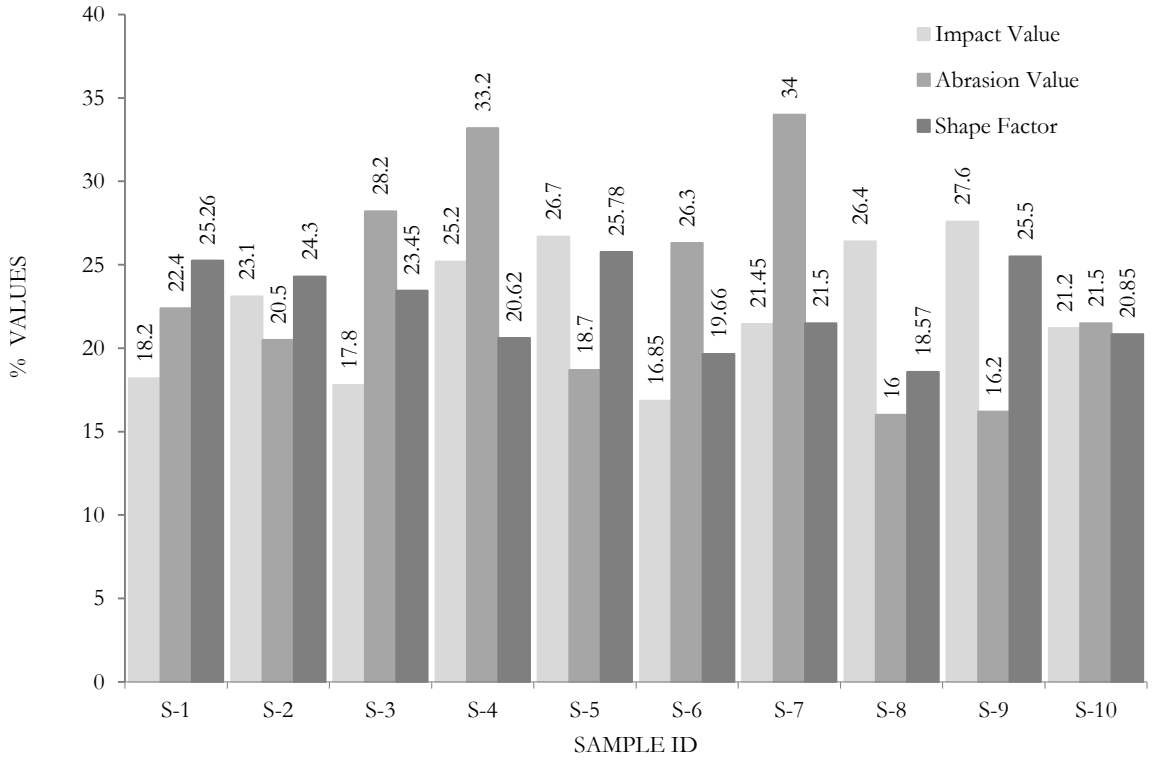

Figure 4. Variation of material quality indices of Toorsa riverbed sediment

Specifications for Building and Road Works (DES, 2020) specifies plasticity index not more than 6% for a fraction less than 0.0425 mm. The experimental study indicates that the Toorsa riverbed sediment contains a substantial amount of coarser particles with very less amount of fines below 0.0425mm and exhibits non-plastic characteristics and does not influence the composition.

However, for sand, the amount of silt content may be crucial to check the quality of sand to be used as construction material.

Granular Sub-Base (GSB)

As per the standard, the grade of each zones for GSB and WMM are indicated corresponding to sieve sizes in descending order and it does not necessarily indicate the single size aggregates. Since aggregates come in various coarse or close graded sizes practically from the natural sources and production plant or so, the Job Mix Formula shall be proposed between the sieve size limits specified by the standards in terms of nominal size. This argument and the relevancy can be understood well by determining the fraction required for each size of aggregates using percentage passing, which is usually calculated in terms of weight (%) as presented in Table 3 through sieve analysis (IS:2720-Part 4, 1985).

Since the variation of riverbed aggregate mix is uncertain, the initial sieve analysis does not provide gradation as per the standard to be used as GSB or WMM materials. This is also true for aggregates produced in different production plants; however, the trial mix may be reduced. The trial-and-error method conducted for producing grades I and II (Figure 5 and 6) of the Bhutan standard is presented in Table 3. Four trials conducted for gradation of GSB show notable gaps among the particles range. This provides ample information on adding and reducing deficit or excess materials sizes respectively to finally obtain the graded proportion which provides JMF.

Table 3. Gradation of GSB-Grade I by trial-and-error method

Sieve size (mm)	% Passing by Weight				Specifications (DES, 2020)		
	Trial-1	Trial-2	Trial-3	Trial-4	Grading curve	Lower limit	Upper limit
75	83.61	90.12	80.10	95.88	100.00	100	100
53	56.02	85.18	69.32	90.61	88.51	80	100
26.5	50.00	79.64	58.71	81.71	70.64	55	90
9.5	35.62	68.58	38.14	67.71	54.47	35	65
4.75	26.59	57.91	34.66	56.51	44.26	25	55
2.36	17.22	33.60	27.20	51.24	33.19	20	40
0.425	12.54	16.80	16.42	30.81	22.98	10	25
0.075	8.36	4.15	1.99	7.41	4.68	3	10

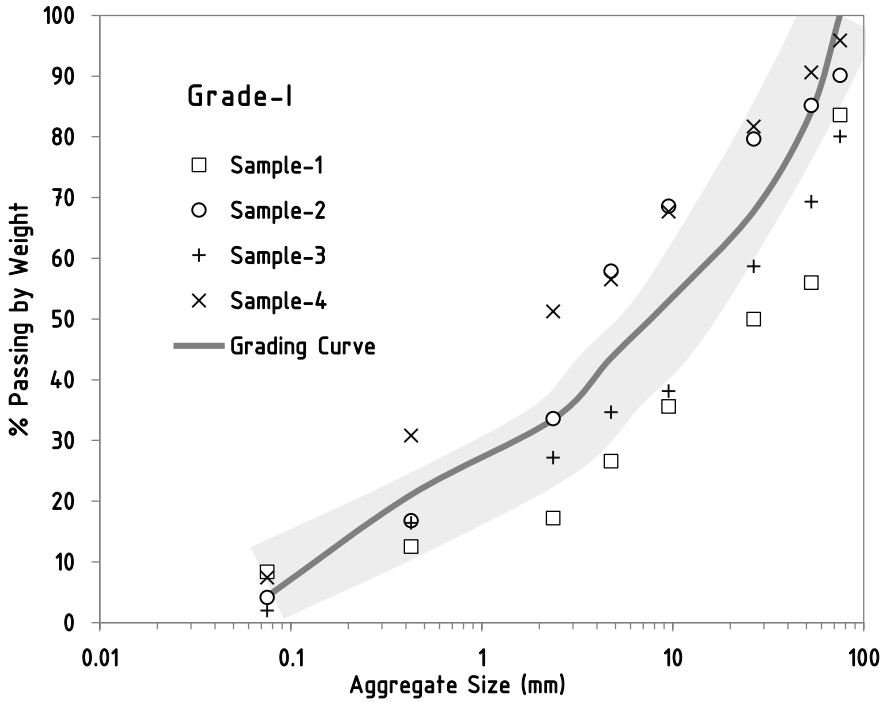

Figure 5. Grading characteristics of GSB grade-I

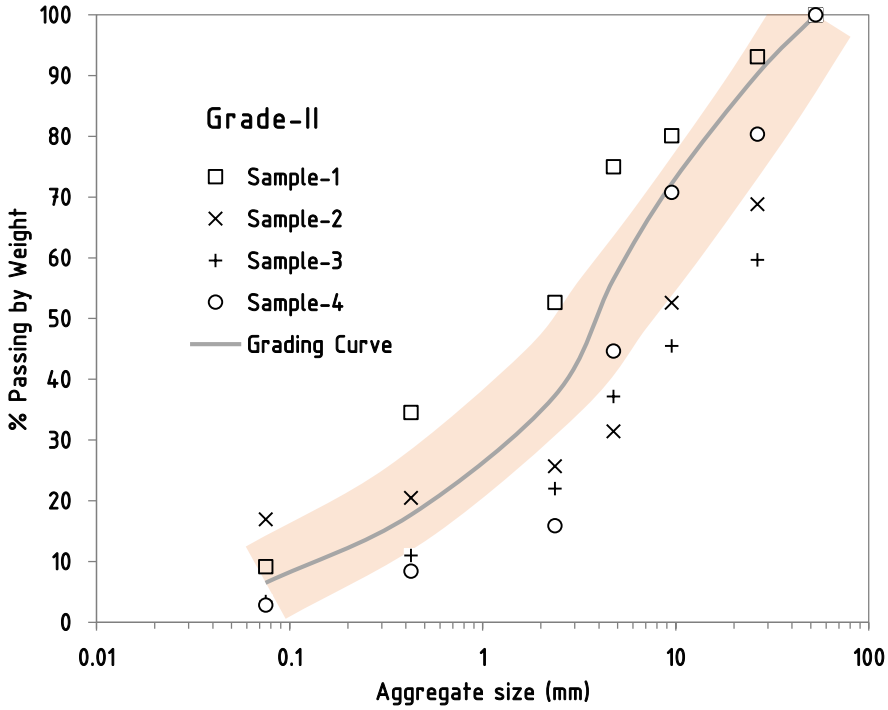

Figure 6. Grading characteristics of GSB grade-II

Wet Mix Macadam (WMM)

The process of gradation is similar to GSB, but the composition of WMM is finer with 53mm downgauge aggregates. The fraction passing 0.425 mm sieve is also not plastic in which the

plasticity is near or equal to zero. Usually, the plastic nature of the soil is more pronounced for fraction passing through 0.075 mm containing clay content and this portion does not fall under the particle range in both GSB and WMM. The trial mix and gradation curve for WMM are presented in Table 4 and Figure 7 respectively.

Table 4. Gradation of WMM by trial-and-error method

Sieve size (mm)	% Passing by Weight					Specifications (DES, 2020)	
	Trial-1	Trial-2	Trial-3	Trial-4	Grading curve	Lower limit	Upper limit
53	95.10	100.00	100.00	91.86	100.00	100	100
45	86.25	69.14	76.05	76.92	96.32	95	100
22.4	81.92	54.07	66.67	74.90	74.23	60	80
11.2	67.23	51.11	65.52	68.68	53.07	40	60
4.75	59.13	44.69	53.74	53.74	35.89	25	40
2.36	13.75	14.32	38.12	31.51	22.09	15	30
0.6	3.58	6.42	26.05	26.15	11.04	8	22
0.075	1.51	2.96	8.24	22.13	3.68	0	8

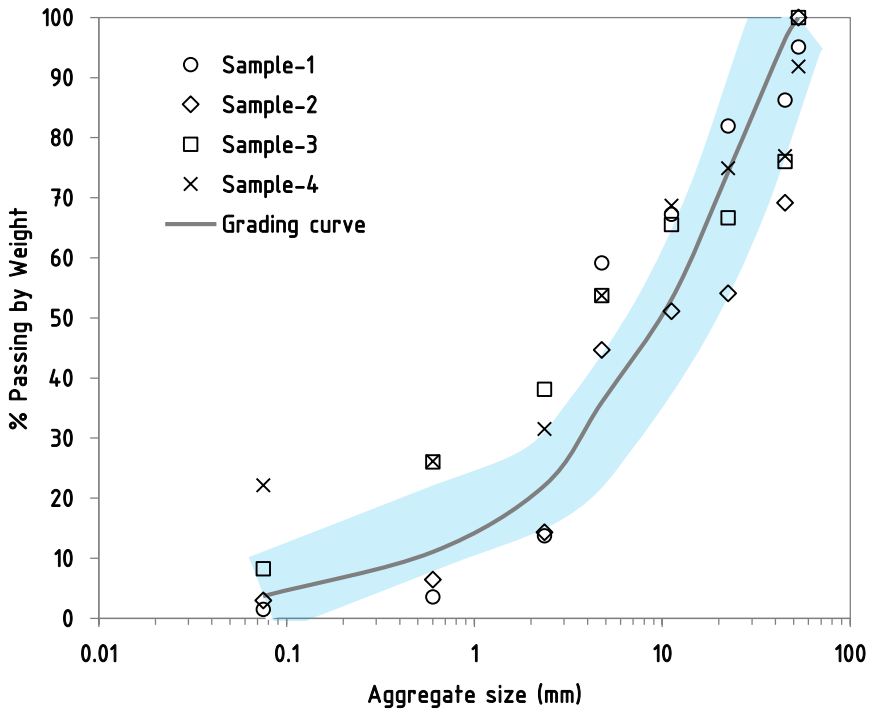

Figure 7. Grading characteristics of WMM

Job Mix Formula for GSB and WMM

The JMF is crucial as it provides the mix design proportions to be executed in the construction site especially when used as GSB and WMM for pavement. To the best of the author's knowledge, the only method of preparing the mix design (JMF) is by conducting sieve analysis for several trial mixes to achieve the grading requirement due to variability of sizes and shapes of natural aggregated apart from the processed one. The JMF provided in this paper is of one instance for a collected sample and may not apply to another batch of samples, however, the reference trail mix can be comfortably determined to reduce the trail mix. The JMF for two-grade GSB grade-I and WMM are presented in the following Tables 5, & 6.

Table 5. JMF for GSB grade-I

Sub-base material			**Gravel**		**Sand**
Sieve Size (mm)	75 – 53	53 - 26.5	26.5 to 9.5	9.5 - 4.75	4.75 - 0.075
Job Mix Formula (JMF) % by Weight	16.66	17.07	15.45	9.76	41.06
Total (% by Weight)			**58.94**		**41.06**

Table 6. JMF for WMM

Base material			**Gravel**		**Sand**
Sieve Size (mm)	53 - 45	45 - 22.4	22.4 to 11.2	11.2 - 4.75	4.75 - 0.075
Job Mix Formula (JMF) % by Weight	3.82	22.93	21.97	17.83	33.44
Total (% by Weight)			**66.56**		**33.44**

Compaction Behavior

Modified proctor test refers to heavy compaction test, an improved version of standard (light) compaction test. The heavy compaction test was conducted to withstand heavy traffic load due to which settlement could be one issue and is conducted as per IS code (IS: 2720-Part 8, 1983). To achieve the desired compaction, the laboratory test determines the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) (Tempa et al., 2021). Figure 8 shows the relationship between the dry density and moisture content for each of the samples. To determine the degree of densification at the site, a field test could be conducted to achieve 98 % of maximum dry density and (+) or (-) 2 % of OMC for embankment, sub-grade, sub-base and base material (DES, 2020). For field density check, either core cutter or sand replacement methods can be used

based on the type of soil. However, for GSB and WMM, the sand replacement method is suitable as the soils are highly coarse compacted.

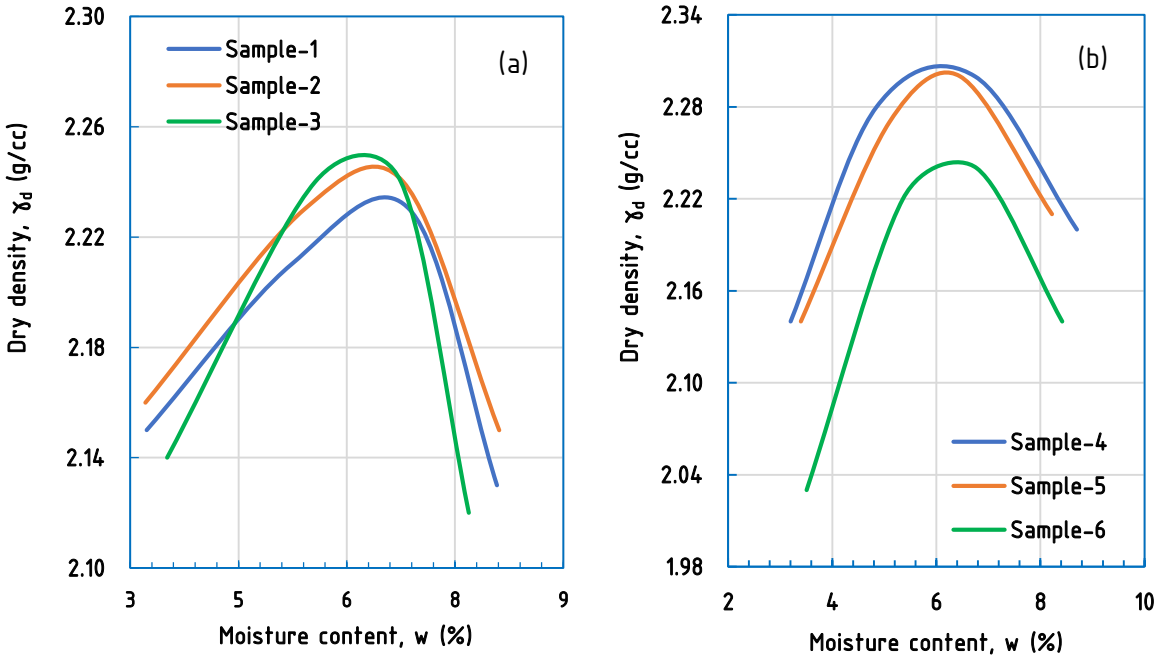

Figure 8. Compaction curve showing compaction behavior of the sediment; (a) GSB, (b) WMM

The Toorsa riverbed sediment exhibits high maximum dry density at low optimum moisture content. This is usually contributed by a larger compaction effort in which MDD is achieved more towards the dry side of the compaction curve (Gopal and Rao, 2000; Mittal S. and Shukla, 2008; Das, 2010; Gurtug and Sridharan, 2015; Yusoff et al., 2017). As per the test and considering an average result, MDD of 2.23 g/cc at 6.4 % OMC for GSB and MDD of 2.32 g/cc at 6.2 % OMC for WMM is suggested as a target value respectively.

Conclusion

The study conducted on Toorsa riverbed sediments for suitability of use in road construction as GSB and WMM indicates that the mechanical properties are well up to the standard requirement with acceptable specific gravity ranges and water absorption potential of less than 2 %. However, the flaky natural aggregates are in a substantial amount and hence initial screening and prior shape test are highly recommended. For JMF, the grading curve presented in this paper may be useful for both GSB and WMM in setting the initial trial mix. The other option could be the use of average values of upper and lower bound of grading curve as specified in the standards to initialize the trial mix. The mix proportion indicated in this paper however can also

be used for batching purposes but gradation should be checked before execution or laying at the site.

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The State of Bhutanese School Building and Classroom

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Abstract: This qualitative study examined the state of physical infrastructure in public schools under Thimphu Thromde. Two higher secondary schools, one each of middle secondary, lower and primary schools were selected drawing lot for the study. Data collected through field visits including a survey of school buildings, classrooms and other school physical infrastructure were analysed using content and thematic analysis. Data analysis revealed cracks on building walls, around windows and doors, broken window panes and floors and furniture, loose and broken railings and doors and windows with broken latches, poor conditions of toilets. The classrooms were overcrowded, lacked emergency exit doors and proper insulation and ventilation, and also had limited ICT provision. To enhance quality education and ensure enabling conditions for learning, school building designs and guidelines need review to include green technology, strengthen quality construction and include smart technologies.

Keywords: School building, teaching-learning, classroom, school

Introduction

According to the MoE (2010) school infrastructure and facilities include buildings, classrooms, laboratory, library, toilets, water, clinics, television, internet, presence and use of chemical, conference hall and cafeteria. It is a fact that school buildings and classrooms are critical components that contribute towards quality education. Physical infrastructure such as school buildings and classrooms impact the daily chores of students and teachers. There is a direct relationship between physical infrastructures such as school buildings, classrooms, toilets etc on the teaching-learning outcome (Ngwaru & Oluga, 2015) and pedagogical process (Dorji, 2020a). The infrastructure must be perfectly put in place for teaching-learning and ultimately leading in shaping the minds of the students in the right approach for a better future and better citizenry. It is education with an appealing set of buildings and classrooms that can help a nation build its human resources to serve in various organizations. For better teaching-learning, the infrastructures need to be well planned and well furnished. In addition, moving space, visibility, audibility, and ventilation are important determinants of teaching-learning in the school. The infrastructure environment such as a hanging pole, cracked wall, broken chair and table, broken floor, and broken window impede effective teaching-learning and quality of education.

The development philosophy of Bhutan, Gross National Happiness (GNH) emphasizes wellness and wellbeing of mental, spiritual, physical, social, economic, political and environmental spheres. In 2010, the MoE implemented 'Educating for GNH' to realise the vision of GNH through education (GNHC, 2019). Education is the core instrument in achieving national vision, goals and values. Such aspirations can be achieved if dramatic steps are taken to improve the physical infrastructure of schools. According to MoE (2016) "the Educating for GNH programme is an approach adopted to ensure the integration of the desired qualities into the education system so as to produce GNH graduates"(p.36). The physical infrastructure of school buildings and classrooms are of paramount importance for quality teaching-learning in the schools. The UNESCO (2015, p.18) argue that "quality education must contribute to the personal fulfilment and happiness of learners as well as to individual and societal well-being"(p.18).

Construction is key organizations for sustainable development (Emami, Marteinsson & Heinonen, 2016). The Minstry of Education(MoE) faces numerous challenges in building school buildings and classrooms of high-quality structure, and seismic resilient (MoE, 2020a). The Twelfth Five Year Plan (2018-2023) recommends the construction organization improve quality infrastructure (GNHC, 2019). If the infrastructure does not inspire the students, teachers and parents the innovation and creativity of infrastructure can be questioned. Students feel happy and proud to study in good school buildings and classrooms. Teaching-learning in good infrastructure has the power to reshape students thinking on infrastructure. The quality of physical infrastructure available in the school will determine the kind of future citizen (MoE, 2014) that will be produced. In this fast-changing digital globalized world, GNH values must be embedded in the school physical infrastructure.

The government view education as one of the fundamental means to achieve GNH and accords the highest priority on education as an engine for nation-building. Investment in school infrastructure is one of the strong frameworks for high performing schools to deliver quality teaching-learning. A good construction framework provides specific objectives for what types of classrooms are supposed to be constructed in schools. It aligns construction with the goal of the nation at par with performance standards across the world. Bhutan construction development policies, especially schools must take account of the emerging economy. As Bhutan drives towards a knowledge-based society, it is time for Bhutan to create an innovative and sustainable infrastructure. It is also time to focus more on equity rather than equality (iDiscoveri Education & REC, 2009).

According to Neilson and Zimmerman (2011) "school construction differs from choice-based policies because students do not have to opt-in"(p.30). However, responsive or effective schools do not look the same. The school infrastructure needs to support the curriculum to meet the target set in the academic plan. Sanoff (1994) argue that "Educational philosopher John Dewey, urged that the learning environment be humane and attentive to individual children's needs"(p.1). Students and teachers spend five to eight hours a day in schools. There is strong evidence that the construction of good schools leads to sustained gains in reading scores for students in elementary and middle secondary schools. To make a meaningful school, the construction organizations need to provide space such as computer laboratories, visual rooms, meeting areas and infirmary, art and culture centre, library, and playgrounds for physical, social, emotional, and academic development for students and teachers. The classroom needs to reflect the student-centric teaching methodologies. The classroom design, furniture set up and the size of the classroom should be suitable for teaching-learning. The recommended ideal size of a classroom is 24 students for primary school and 30 students for secondary school (iDiscoveri Education and REC, 2009; Dorji, 2020b). School buildings and classroom space convey the message of inner life, social values and activities of who created building and who used building (Sanoff, 1994).

According to the Royal Education Council (2018), buildings occupy a huge share of land use, water consumption, energy use, waste production, and carbon dioxide emission. It is important to consider a green building for sustainable development. The green building consists of insulating walls, automatic light shut-off switches. Green building uses a light-emitting diode (LED) bulb and proper heating, ventilation, and air-conditioning systems. The construction materials are environmental and user friendly. There are wide ranges of benefits for adopting the construction of green buildings in schools. According to Varma, Chaurasia, Shukla and Ahmen, (2014) "green buildings account for improving environmental footprint by reducing energy use by 30-5-%, carbon dioxide emissions by 35%, waste output by 70% and water usage by 40%"(p.1). Today green building architectures are widely used in schools with natural daylighting and views to promote the well-being of teachers and students (Varma et.al., 2014; MoE, 2020).

The study on the inviting classroom under the quality of school education in Bhutan: reality and opportunities by the iDiscoveri Education and REC (2009) found that many classrooms lack essential design, resources, and infrastructure for an engaging and comfortable environment for teaching-learning. The study revealed that on average the classroom dimension was 22 feet by 23 feet. Most of the classrooms were overcrowded with the sheer size of students and small classroom space. The study also revealed that there was a leaking roof and cracked walls in various classes.

Classroom lighting was insufficient. The study recommended the MoE supply age-appropriate furniture for students and proper lighting in the classrooms.

A recent study by Dorji (2020a) on Gender Responsive Physical Infrastructure and Facilities: A Case of Secondary School Under Thimphu Thromde, Bhutan revealed that there was an absence of adequate gender-friendly toilets with regular clean water, soap, sanitary bins and wear for menstrual hygiene. The number of toilets was not adequate due to the sheer size of students and limited recess time of 10 minutes. The study, therefore, recommended mounting workshops to create awareness on gender-responsiveness and gender-friendly toilets in the schools.

Although the school buildings should maximize learning, promote intellectual, creative growth, and lift the spirits of teachers and students, the lack of financial resources to create good essential infrastructure in schools is a challenge (MoE, 2020a). Schools cannot remain deficient in good school buildings and classrooms in the 21st century (MoE, 2014). The Sustainable Development Goal 4 'ensure inclusive and equitable quality education and promote lifelong learning opportunities for all requires a collective commitment of the education sector through bold and innovative actions.

Significance of the Study

The vision of Education 2030 reaffirms that 'education is a public goods' (UNESCO, 2015, p.12) and merit goods (MoE, 2013). Education is a fundamental human right for people. The study will be significant to draw policy attention to school design and construction. The findings from the study can sensitize policymakers, education officials and construction organizations that engage in building and classroom construction. The outcome and impact of teaching-learning are dependent on the quality of an appealing school building and classrooms.

Objective of the Study

According to UNESCO (2015) "quality education should not be narrowly defined by just learning outcomes that are most easily measured"(p.18). The quality of schools is mainly determined by effective physical infrastructure and resources acquired, managed and maintained (MoE, 2016). Therefore, the objective of the study is to examine the physical school infrastructure and resources as the basic determinant of the quality of teaching-learning and provision of holistic education.

Research Question

1. How are the existing physical infrastructure such as school buildings and classrooms conducive to the quality of teaching-learning?

Data and Method

The study was exploratory using qualitative study techniques. The data was collected through field visits including a survey of school buildings, classrooms and other school physical infrastructure. The field visits including a survey of the school building, classroom and other physical infrastructure were carried out to gain first hand experience in a natural setting of the school building, classroom and identify common patterns in structure and displays (University of Bradford School of Management, n.d).

There are four public higher secondary schools, five public middle secondary schools, four public lower secondary schools, and five public primary schools under the Thimphu Thromde after drawing of lots, two higher secondary schools, and one each from the middle secondary schools, lower secondary school, and primary school each were randomly selected for the study.

The schools were coded as 001, 002, 003, 004 and 005 to hide their identity. Data collected through field visits including a survey of classrooms and other school physical infrastructure were analysed using content and thematic analysis.

Data collected through field visits including a survey of school buildings, classrooms and other school physical infrastructure were matched with secondary data from a desk review of studies in the past to examine similar trends and conclusions.

Findings

Upon analyzing the observation data using the content or thematic analysis, twelve themes were drawn as follows:

1) Location of building

In schools 001, 003 and 004, school buildings were found close together and there were no emergency exit doors in classrooms during a disaster. Schools may have risks from fire, but fire safety equipment was absent in all schools. Fire extinguishers were hardly seen in the schools and the ones available fire extinguishers in the schools were non-functional. A separate water tank and water distribution for firefighting were not available in the schools. There is an absence of vehicular access for students, teachers, deliveries and access for ambulance and fire fighting vehicles in many schools. For instance, schools 001 and 003 were not accessible to vehicles due to the presence of walls, steep steps, buildings, trees and canopy among many others. Safety measures are not available to prevent potentially disastrous accidents. Access to and within the school are not inclusive for students and people with disabilities and elderly people.

2) Condition of buildings

To facilitate better teaching-learning and safety, school building walls and windows should be free of cracks. However, it was surprising to see cracks on the walls of new buildings, around the windows and door, and toilets in schools 001, 002, 003 and 005 as shown in Figures 1 and 2. The presence of such cracks on the wall might encourage students to practice such a culture in near future. Students, teachers and school management deserve safety standards at schools.

3) Natural ventilation

All school buildings in Bhutan have the same structure. The school have large windows and doors for natural ventilation. Classroom lighting was found to be insufficient in the old-school building. According to MoE (2020a) natural ventilation control internal temperature during summer. However, the present natural ventilation does not control temperature during winter especially in schools in colder regions of Bhutan. It was observed that there was no proper winter heat insulation in the schools. To create a positive physical learning environment, proper winter heat insulation was necessary for the classrooms.

4) Building floor and lighting

During the observation, the researcher observed a few broken windows, loose and broken railings, doors without latches, broken wooden floors and broken furniture. In school 001, 003 and 005 there were few graffiti on the walls. The school walls were not painted uniformly. There is no policy regarding the school wall and classroom painting. All old-school building does not have proper ventilated or good lighting facilities. To facilitate better teaching-learning school buildings need adequate and natural classroom lighting. LED bulbs were not used in the classroom while most bulbs would not light due to loose connections or the sockets or bulbs being fused.

5) Tall trees

During the observation, 003 school was covered by tall and big trees. The school was proud of its natural sources. A beautiful green campus is essential for teaching-learning. The researcher found the environment was welcoming and inviting. Under such an environment, teaching-learning became an enriching and joyful experience. Deciduous trees provide more shade in summer and help prevent direct summer sun into the building and might allow the sun in the building during winter. However, the school must take precautions about the big trees. There could be a risk to students and school infrastructure especially during autumn and spring when the weather gets stormy and windy. Old branches could break and trees might fall. The falling leaves of deciduous trees add to the social workload for students during autumn and winter sessions. All schools carry out ten to fifteen minutes of social work by students before the start of the classes.

6) The physical appearance of school building and classroom

The infrastructure such as broken windows, door, floor, rallying and crack walls in the observed schools required immediate maintenance. According to the MoE (2016, p.11) argue that "the maintenance and improvement of the school buildings, property and grounds, education materials and equipment are crucial. The safety and security of the school properties must be insured" to foster healthy learning and growth. The school infrastructures were not seismic resilient, user-friendly, and of high quality with space for academic, technology, physical, social and emotional development of teachers and students. School or classrooms are the second home for teachers and students where they spent more than six hours in a day interacting with each other.

Around 10% of classrooms have a project and few projectors were not functioning. In the 21st century, schools cannot be separated from technology in education. However, it was observed that classrooms are not equipped to hold ICT based teaching-learning. The basic fundamental of teaching-learning was to deliver high quality and raise the bar of teaching-learning in the schools. According to UNESCO (2015), digital technologies are demonstrated in the classroom across the globe to empower teachers and lifelong students to be innovators, responsible and competent citizens in the globalized world. With effective technology provision in the classroom, teaching-learning outcomes can be enhanced, deepened and create a knowledge based GNH society.

(a)

(b)

(c) **(d)**

(e) **(f)**

Figure 1. School building infrastructure

(a) **(b)**

(c)

(d)

(e)

(f)

Figure 2. Classroom infrastructure

7) Staffroom

All staff rooms were found with the same kind of structure across the schools. Staff rooms are spaces for the teachers to interact and share their practices, knowledge and socialize. A staff room is also a place where teachers prepare their daily lesson plans, check students' assignments, read and carry out projects.

The staffrooms were crowded that there is no room for privacy, silence, and an appropriate academic station. Nearly, 20% of the current staff room has a handful of adequate storage shelves and cupboards available for teachers. Around 90% of schools have no proper lockers to keep property safe in the staffrooms. The present staffrooms do not promote academic cultures such as concentrating teachers on work, reflection and critical inquiry on their teaching practices, and small group meetings with students.

8) An alternative source of energy

All schools depend on hydropower as the main source of energy. Other alternative sources of energy such as solar energy were not seen in the schools. The school have not prioritized the use of solar energy to heat rooms and water during winter and cool rooms during summer.

9) Dining hall and conference hall

Since all public schools under Thimphu Thromde are day schools, there was no dining hall for lunch. All students were found eating lunch in their respective classes or the assembly ground or parking area or in the shade of trees. During rainy and windy days, students cram the corridors and classrooms for a place to dine. Dogs were found around students during lunch break.

In many cases, Multi-Purpose Halls were occupied with other activities in the schools. There is no cafeteria, guest room, vocational room included in the school building plan as shared by four principals during the casual discussion. Conference halls where staff meetings and professional development sessions could be held were not available in the schools. Often meetings and professional development programmes were conducted in the school multi-purpose halls. Since there are no acoustic materials used in the Multi-Purpose Halls, speakers' voice is scattered or echoed making it inaudible and unclear.

10) Health room

All schools have a dedicated health room with one or two beds. The heath room does not have attached washrooms. In many cases, both boys and girls were kept in the same rooms. The basic medicinal needs and first aid kit were found in the school. Health rooms are located not close to the staffroom or principal office to monitor sick students.

11) Class size

An inviting classroom includes age-appropriate furniture, class set up and the size of the classroom. On average 10% of classes observed were not adequately equipped with age-appropriate furniture. For instance, schools 001 and 005 had tables and chairs too small for grade 6 students and students were sitting too close with each other, thus limiting space to work during the teaching-learning process. The classrooms were found overcrowded due to the sheer size of students. According to MoE (2020c), the number of students in each class is one indicator that measures the quality of education across the world.

12) Toilets

It was observed that toilets were all accessible and convenient for the students. There were separate toilets for boys and girls with the same structure. However, in schools 001, 002 and 003 toilets were located close to each other and there was no privacy. There is an absence of sufficient

lighting in the toilets. The urination provision is open and there is no separate compartment to pee. Toilets were not gender responsive and gender friendly as it does not address the needs of boys and girls. According to MoE (2020a) the minimum number of toilets planned should be one per 20 girls and one for female staff; one toilet plus one urinal per 40 boys, and one for male staff. When possible, this provision shall be doubled for primary schools (i.e. 1 toilet per 10 girls and 1 toilet plus 1 urinal per 20 boys). At least one toilet cubicle should be accessible for staff and children with disabilities, preferably one for females and one for males (p.117).

However, during observation, the researcher observed the recess period in the schools is ten minutes and the lunch break in school is around 30 to 40 minutes which is insufficient for the students. Female students need more time in the toilet due to biological reasons and thus the time taken by girls is comparatively longer than that of boys. The pad bin for disposal of used sanitary pads was not found in the girls' toilets. Special provisions were not seen for girls' toilets for sanitary disposal. Many girls coming from poor socio-economic family backgrounds cannot afford sanitary pads and hence are often found to be missing classes during menstruation. This will affect their learning outcomes and classroom teaching-learning concentration. Safe, healthy and secure school environments safeguard students from health hazards. The current sanitation and toilets might not enable students to become agents of change for improving sanitation and hygiene practices in communities.

Discussion

In the past six decades, the MoE has done more in the quantity of school, but much remains to be done on the quality of the school. Quality goes hand in hand with quantity in nation building. According to the Population and Housing Census of Bhutan (2017), the population growth rate from 2005 to 2017 was 1.3% per annum. The total fertility declined from 2.6 children per woman in 2005 to 1.7 children. The median age was 26.9 years, meaning half of the Bhutanese population are younger than 26.9 years in 2017. The Ageing Index is 22.7 years indicating an ageing population in Bhutan. Soon Bhutan might experience lower population growth and might lead to a decrease in the working population and an increase in the ageing population (NSB, 2018). A decrease in the working population and the ageing population will have problems not only for the demand side but also for the supply side in terms of school physical infrastructure and classrooms. Thus, the MoE can't go on building schools everywhere but can improve the quality in terms of physical infrastructures, classrooms and facilities in the school.

In a digital age schools in Bhutan are found not embracing enough technology to enable a technology enriched teaching-learning process. Technology such as computers, projectors with

free access to the internet is not incorporated in the Bhutanese classrooms. The Covid-19 pandemic has left schools, students, parents and teachers with no choice but to turn to technology. Integrating technology in the classrooms would provide a platform and learning space between teachers-students, teachers-parents, parents-children, and students-students for more effective communication and ensure quality in teaching-learning. Technology is a major tool in terms of pedagogical resources and in terms of connecting with the younger generations. Technology provides students with easy access to information, educational resources and fun opportunities to practice what they learn. Without access to technology or ICT facilities in school, the nation cannot move forward because learning becomes less versatile and prevalent.

The fourth industrial revolution is driven by advanced technology such as the internet of things, robots, drones, augmented reality, virtual reality, 3D printing and artificial intelligence. It would affect the country in general and individuals in particular. The available technology in the classroom is not enough to take the opportunities that come with it. The Bhutanese students and teachers are passive technology consumers rather than content producers or application developers. In many cases, teachers and students were mostly hooked by social media or continued to bank on agriculture, tourism and hydropower instead of banking on technologies. The ICT enabled knowledge based GNH society through education would just remain a vision without many practical programs, plans and reforms in the schools and classroom like Singapore has for instance (Dorji, 2018).

The classroom size is the main determinant of delivering quality education (MoE, 2020c). The current classroom sizes are congested and unfortunately tolerated by the school as a normal practice in teaching-learning. There is limited space for the free movement of teachers and students. Currently, the major concern of education in Bhutan is the provision of quality education. The quality of education cannot be improved if the MoE maintains the current number of students in the class. The rationalization of physical infrastructure and facilities would help enhance quality by maintaining the right class size (GNHC, 2018).

School buildings and classrooms must be safe, happy and healthy with adequate physical, social, spiritual, cerebral and emotional conditions for learning and playing. Safety is an emerging issue due to the sheer size of students, teachers and staff in both rural and urban schools. It has been proven time again that schools are the most affected during the disaster and natural calamities. Around 117 schools were damaged by the earthquake in 2009 (MoE, 2014). Schools under Thimphu Thromde are no exception to disasters such as fire, earthquakes, flash floods, human error and poor maintenance. Right now, school construction is half hearted at best.

According to Dorji (2020c), "the teaching profession in general suffers from lack of access to adequate resources and facilities, compared with other professions in Bhutan"(p.60). Without essential infrastructure and facilities in a school can bring job dissatisfaction among teachers, school management and learning dissatisfaction among parents and students (Kihara, Kamau & Gichuhi, 2018). This will accelerate challenges in terms of addressing efficiency and quality of education. The quality of any good school is the result of how physical infrastructures are constructed and how conducive are physical infrastructures for teaching-learning. Physical infrastructure such as school buildings and classrooms can be one standard for the Bhutan Professional Standards for Teachers to prepare nationally rooted and globally competent productive citizens. Accountability towards physical infrastructure such as school building, classroom and others are not visible. The students, teachers, parents, school managers, cultural specialists, sociologists, spiritual seekers, civil society and local leaders are better and able to understand their concerns and needs (Dorji, 2020).

The findings and discussion of the study were consistent with the previous study done on the inviting classroom under the quality of school education in Bhutan: reality and opportunities by iDiscoveri Education & REC (2009). After eleven years later, this study discovers similar shortcomings in its findings and patterns. The gap remains the same because there was a lack of clear communication and coordination among different stakeholders. There was a lack of a clear shared goal, objective and vision for the education system. In Bhutan, the poor physical infrastructure of school buildings and classrooms were unfortunately tolerated and assumed as normal practices. Therefore, the MoE need to engage all relevant stakeholders with a compelling vision and set a clear goal and translate goals to achieve the vision of education. Teachers, parents, students, education officials, bureaucrats, policymakers. civil society and private organizations were not aware and hardly recognize its impact on pedagogical practices and learning outcomes.

Finding from this study confirmed an earlier study of Dorji (2020a) on Gender Responsive Physical Infrastructure and Facilities: A Case of Secondary School Under Thimphu Thromde that there was the absence of gender-responsive and gender-friendly toilets in the schools.

Conclusion and Recommendation

Gauging by the evidence of the study all school buildings have the same structure. The classrooms were found overcrowded in many cases. New school buildings have large windows and doors. Proper winter heat insulation and summer heat cooling is missing in all schools. Some school environment is welcoming and inviting with deciduous trees and flowers around the schools. All schools have a dedicated health room with one or two beds. But does not have an

attached washroom. All schools have staffrooms of varying sizes and conditions with no room for privacy and personal academic stations. There is no emergency exit door for classrooms or working fire extinguishers in cases of emergencies. There is an absence of vehicular access for students, teachers, deliveries and access for ambulance and fire engines in many schools.

The LED bulbs were not used in the classroom to save energy. A sufficient lighting system is absent in the toilet. The urination provision is open and there is no separate compartment for both boys and girls. The toilets floors are wet and slippery. There is no menstrual hygiene management room with continuous clean running water and proper drainage of wastewater inside the toilets. The proper disposal of the pad bin was not found in the toilets. There were no proper dining halls for lunch in the schools. In many cases, Multi-Purpose Halls are occupied with other activities in the schools.

With all its shortcomings, the Bhutanese education system contributed well to the nation building process. While MoE has tried to improve the quality of education with many underlying challenges, it is crucial to move the education system forward with the current global trends of physical infrastructure that created a conducive learning environment. If education fails to address the gap of physical infrastructure, the success of addressing the quality of education, innovation and creativity can be undermined.

To ensure quality teaching-learning in the school, the study recommends the following to the MoE:

- revisit, rethink and review the current school building designs and guidelines without being territorial, defensive and sensitive to criticisms. The school building design and guidelines need to ensure not only on paper but in practice and implementation. The construction company and Thromde should be held accountable for poor quality buildings and infrastructures. Half-hearted approaches are not enough.
- model school buildings and classrooms incorporating green technology and climatic conditions that students can look up to rather than reinforce the conventional way of constructing schools.
- explore cost effective school building designs that are eco-friendly, safe, secure, easy maintenance and energy efficient. Incorporate temperature insulation building, guest room, vocational room, conference hall and cafeteria. COVID-19 has extended academic sessions throughout the year.
- create smart classrooms incorporating ICT, overhead projector, white screen and computer screens along with the green board. In the era of science-based technology,

classrooms need to be equipped with technology based teaching-learning. Access to the Internet in the classroom should be a basic human right of students and teachers. The COVID-19 has left school with no choice but to turn to technology. Technology and education cannot be separated or avoided in the 21st century.

- use LED bulbs in the school to minimize cost. Rainwater harvesting systems and weather stations should be incorporated with the construction of school buildings for holistic teaching-learning.
- explore solar power for heating and cooling classrooms. This could help the private sector to grow and generate employment opportunities and investment opportunities.
- ensure continuous quality support to the Water, Sanitation and Hygiene (WASH) program to strengthen health and hygienic habits and addresses the needs of adolescent girls in the school. The infrastructure such as toilets, clean water and better securities are the immediate attention required for gender sensitivity infrastructure. The immediate goal of WASH needs to ensure that school managers, students, teachers and staff can drink water right out of the tap.
- construct gender responsive and gender friendly toilets addressing the needs of boys and girls in the schools.
- staffrooms need to be designed in such a way that teachers are grouped with their subject department in cubicles. Each teacher should have one room space of 4-5 people for discussion with a proper locking system. Small group break-out spaces for teaching-learning need to be considered. Good and effective staff rooms can enhance quality teaching-learning and improve the working environment of teachers and staff.
- involve critical, knowledgeable, aptitude and competent students, parents, teachers, school managers, local leaders, civil society, private organizations and municipal staff for decision making process and their voices must be heard and taken into consideration. Rather than working in silos or top down and technocratic manner, it is necessary to work together at this juncture for greater collaboration and pursue education from a holistic approach to serve the greater cause and to instil a shared sense of community or responsibility. It is only through dialogue, discussion, reflection and consensus that makes to move forward to create robust and resilient school buildings and classrooms. In addition, the types of material used and engineering methods also determine the resilience and quality of infrastructure.

Investment in education is considered a long-term investment and foundation for all development by all nations. The education budget needs to be enhanced and targeted better in school and classroom construction. Therefore, the quality of education is a multidimensional evolving concept and cannot narrowly be defined by learning outcomes alone. The school infrastructure and facilities: buildings, classrooms, laboratory, library, toilets, water, clinics, television, internet, conference hall, cafeteria, guest room, playground, presence and use of chemical can be the main standard of the Bhutan Professional Standards for Teachers.

Limitation of the study

The study was carried out in public schools under Thimphu Thromde, Bhutan. Although the study used a small sample size, an honest effort was shared to reach a reasonable conclusion. Thus, the study can be generalized to some extent for all public schools in Bhutan.

The location and orientation of buildings, hazard and disaster assessment, building security and access, water facilities and distribution networks, structural materials, water quality and plumbing, power distribution, parking space, footpath, administration unit, laboratories, gate, compound fence, staff quarters, counselling room, storerooms for books and stationery, examination rooms, football field, volleyball court, basketball court and indoor games in the campus could not be studied due to limited expertise, time and resource. It is necessary to examine in action with a checklist to assess the quality of the school. The views of students, teachers, parents, policymakers, bureaucrats and construction organizations could not be collected. The national-level study needs to be carried out in the country to further generalize the findings and discussion.

Future researchers are recommended to adopt a mixed-method approach with a larger sample size. The mixed-method should comprise a survey questionnaire for students, teachers, parents, policymakers, bureaucrats and construction organizations; focus group discussions with the same groups of participants and interviews with policymakers and construction organizations are recommended to further validate the current findings and discussion.

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Bhutanese Architecture Guideline (2014): Architects' Perspective

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Abstract: Bhutan's isolation from the external forces of modernization endured till the 1970s. The essence of traditional architectural elements in the form of scale, proportion, details, or use of materials were glorious, depicting the rich architectural heritage. However, owing to modernization, the import of modern materials and labor, the dependence on modern technology, ignorance of traditional Bhutanese architecture and the shrinking number of artisans have resulted in the deterioration of our traditional building styles and practices. Ultimately in 2002, "Traditional Architecture Guidelines" was published in an attempt to streamline the construction of various buildings with the appropriate architectural style which was then updated with the "Bhutanese Architecture Guidelines 2014" (BAG 2014). The study attempts to present the interaction of the guideline with the architects and present their expressions and need analysis for a possible review in the hope to strengthen the BAG 2014 and aid in Bhutan's effort towards the conservation of the traditional architecture. A mixed-method, convergent design was adopted for the study. Quantitative data were gathered from 100 architects and qualitative visual survey inferences were drawn from 46 case buildings. Findings revealed that the institution of the guideline has brought about positive transformation to the built environment of Bhutan, although with few glitches in terms of failure to justify traditional entitlement, ambiguity in the guideline and ambiguity in the traditional practices. Likewise, the majority of the respondents support the review of the existing guideline. The study recommends a more comprehensive and unequivocal guideline, with room for flexibility to foster innovation and creativity, yet preserving the rich architectural heritage of Bhutan.

Keywords: Bhutanese Architecture Guidelines (2014), visual survey, architecture, guideline, questionnaire

Introduction

Since the onset of inhabitation of space by the people, socio-cultural, political preferences and the regulations concerning the form and performance of buildings have always been part of an inevitable process in shaping the built environment (Imrie & Street, 2011). Imrie (2007), in an interview, captured an expression by an architect towards building regulation: "I think a lot of our architectural life is actually dominated by regulations. I mean, you're prescribed, almost as soon as you start building, by regulations of one sort or another" (Imrie, 2007, p.925). According to Ben-Joseph (as cited in Fischer & Guy, 2009) codes and regulations have been identified as highly

influential in shaping urban places and architectural form. The architectural practice is intertwined by building regulations, codes and rules that are formulated to produce predictable outcomes to mediate the interest of private and public entities (Imrie & Street, 2011).

The primary reason for the developed nations (Europe, America, Canada, Australia) (Visscher & Meijer, 2006; van der Heijden & de Jong, 2009) to formulate regulations for the built environment is solely rooted to safeguard the safety and the health of their inhabitants (Visscher & Meijer, 2006). As a result, many established their regulation owing to government's intervention to the chaotic, unsanitary and unhealthy living conditions of the 19th century (van der Heijden & de Jong, 2009). Visscher & Meijer (2006) noted that most West-European countries call their regulations, "performance based" and they share similar goals and aspirations though with few variations. These regulations cover a broad range of topics on safety, public health, amenity, accessibility and sustainability (van der Heijden & de Jong, 2009; Oboirien & Windapo, 2020). Over the years, the building regulations in these countries, especially in the UK have grown in scope and complexity, as a result of a shift from the mere health and safety-related issue to the boarder aspect of energy efficiency and sustainability (Fischer & Guy, 2009).

Likewise, Bhutan has a range of regulations that shape the built environment such as Bhutan Building Rules (BBR 2018), development control regulations of *Thromdes* (municipal), Bhutanese Architecture Guidelines (BAG 2014), Bhutan Green Building Design Guidelines (BGBDG 2013) and other planning regulations. BBR 2018 and development control regulations of municipalities could be categorized as a typical performance-based regulation, much like the ones described in the preceding paragraph as they are established to promote settlements and buildings that are safe, functional, accessible and consistent with the traditional architecture of Bhutan. Whereas, the BAG 2014 is a unique contextual guideline that primarily dictates the form and entitlement of the buildings to harmonize the structures with the traditional architectural design and proportion. It would be beyond the scope of this work to cover and discuss all the regulations that influence the urban and architectural form. Therefore, this research will uncover only the interaction of BAG 2014 with the architects. The following section covers the historical development of the BAG 2014 in Bhutan.

Bhutan has remained in isolation until the 1970s sustaining its centuries-old illustrious culture and tradition (Saboo, 2016)- one component being the long-established traditional architecture (Chettri et al., 2020), free from external influences. The glorious essence of traditional architectural elements in the form of scale, proportion, details, or use of materials have come under constant threat with Bhutan getting engulfed in the never-ending race of modernization and

urbanization like any other nation (Ministry of Works and Human Settlement, 2014). This led to the construction of multi-storied buildings and the much-needed momentum was provided by the easy accessibility of materials and labor across the border towns of Bhutan and India (Department of Urban Development and Housing, 2002). Consequently, buildings sprouted which were out of context in terms of cultural, climate and as well as local resources of Bhutan (Aia & Bertaud, 1976). The heritage at that time was in danger of being eroded with the import of cement, steel and architectural concepts alien to the kingdom's culture and natural environment (Department of Urban Development and Housing, 2002).

Ultimately in 1993, "An Introduction to Traditional Architecture of Bhutan" was published and it served as an important reference on the Bhutanese architecture. During this time, efforts were undertaken to fuse the traditional architecture with modern material and methods, however, results were not encouraging owing primarily to the absence of any written guidelines. As a result, erstwhile National Urban Development Corporation which was mandated to promote the architectural heritage of the Kingdom published the first-ever guideline, "Traditional Architecture Guidelines" in an attempt to streamline the construction of various buildings with the appropriate architectural style. The guideline emphasized the organization of traditional features, their modes of construction, *thopthang* (entitlements) and minimum requirement of traditional features depending on the type of building (Department of Urban Development and Housing, 2002)

With the changing times, there was a need for a comprehensive guideline that would cater to the new, bigger and high-rise building of the modern era as it was beyond the scope of the previous guideline (Ministry of Works and Human Settlement, 2014). Subsequently, in 2014, the Ministry of Works and Human Settlements published the BAG 2014 intending to support the construction, repair and restoration of traditional structures and construction of modern buildings that are harmonious with traditional architectural design and proportion.

The institution of the necessary statutory guideline by the Royal Government of Bhutan has possibly brought about positive transformation to the built environment which aligns with the primary objective of BAG 2014 to orient sustainable development in the country without compromising on the rich architectural heritage. Conventionally, the building regulations have a strong correlation with the positive benefits and they should be reasonably rigid and adequately flexible (Nagpure et al., 2016).

However, there is limited knowledge or understanding of how development professionals (such as architects) interact and understand the rules and regulations related to the construction of

the built environment, and how this interaction shapes the different elements of the design process (Imrie & Street, 2011; van der Heijden & de Jong, 2009).

Therefore, this study attempts to fill that gap by trying to uncover the interaction of architects with the BAG 2014. At the same time, the study also attempts to understand the impact of the institution of the guideline to the built environment of Bhutan and lastly the need analysis along with recommendation is presented for a possible review in the foreseeable future. The BAG 2014 is the key constituent in Bhutan's effort to ensure conservation and development of the traditional architecture and its associated values (Ministry of Works and Human Settlement, 2014). To Bhutan, conservation and development of cultural heritage is of national importance (Thinley et al., 2021) and thus conserving the traditional architecture is one of its component. This study is expected to strengthen the BAG 2014 and present opportunities for improvement. The study revolves around the following main research questions:

- What is the possible transformation/impact brought about by the institution of the architecture guidelines?
- What are the expressions of architects towards the BAG 2014?
- What recommendations, if any, are necessary to the existing BAG 2014?

Data and Method

This study employs a mixed-method design (convergent design), reaping the advantage of both qualitative and quantitative methods in addressing complex problems. In a convergent design approach, the qualitative and quantitative data can be compared for data validation or data triangulation (Demir, 2018) as illustrated in figure 1.

Non-probability purposive sampling method was adopted for the survey questionnaire in part A. A total sample size of 229 (at the time of administering the questionnaire) encompassing architects who were registered with the Construction Development Board of Bhutan were invited through email to participate in the survey. In part B, a visual survey/case study was undertaken in Thimphu and Paro as they portrayed the balanced mix of old and new residential buildings. Although the study deals with the association of BAG 2014 with the architects, the year 1993 was considered as the threshold line to determine pre- and post-impact of the guideline. This assumption attempts to filter buildings that came before any sort of reference or guideline on traditional architecture and it relies on the fact that the residential buildings built before 1993 were not influenced by the guideline as it was only in 1993 that an importance reference, "An Introduction to Traditional Architecture of Bhutan" was published. Thus, a purposive sample size

of 46 buildings (before and after 1993) from different regions of Thimphu and Paro was identified for the survey.

The core assumption of this form of inquiry is that the integration of qualitative and quantitative data yields additional insight beyond the information provided by either the quantitative or qualitative data alone (Creswell & Creswell, 2018).

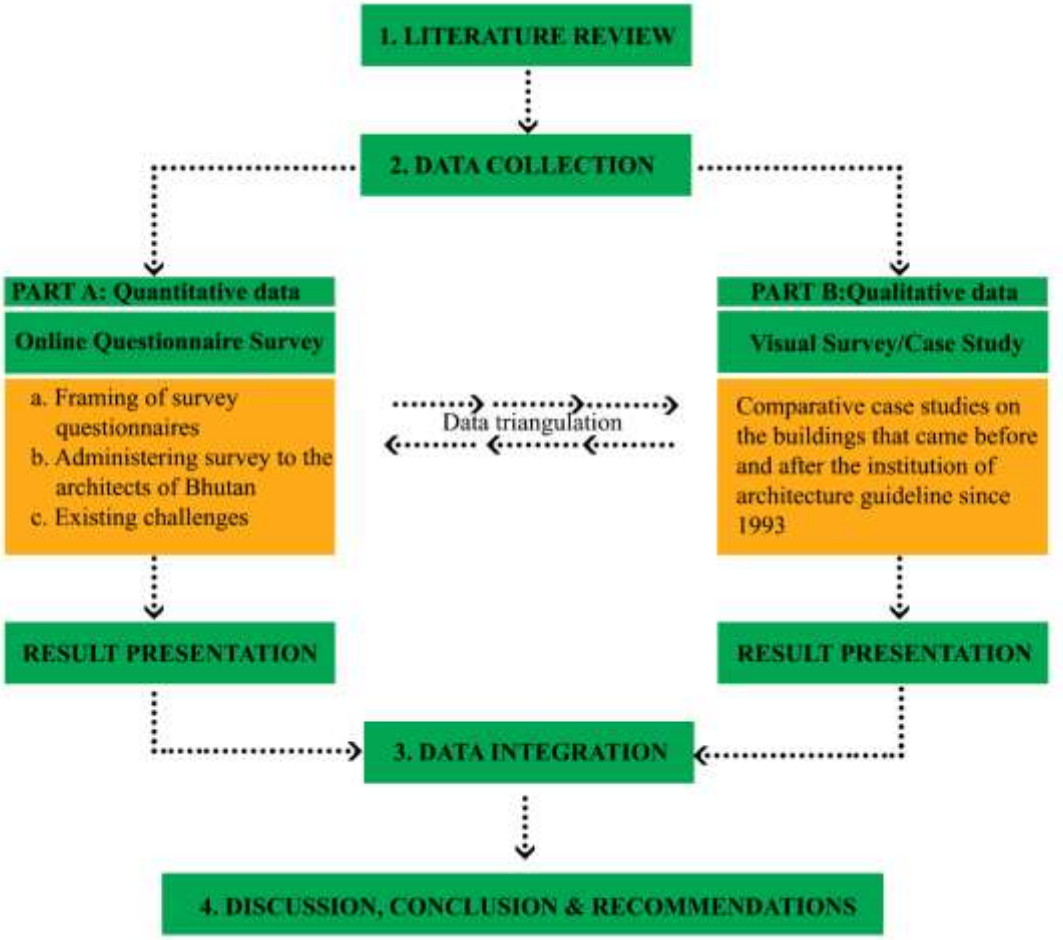

Figure 1. Methodology flow chart

Results and Findings

Expressions/Observations of Architects

Online questionnaires were administered to 229 architects out of which 100 responded. Figure 2 illustrates that the majority of the workforce is working in the private sector (48%) which is followed closely by 35% in government organizations. The remaining 16% of them are working in other categories such as non-governmental organizations (NGOs).

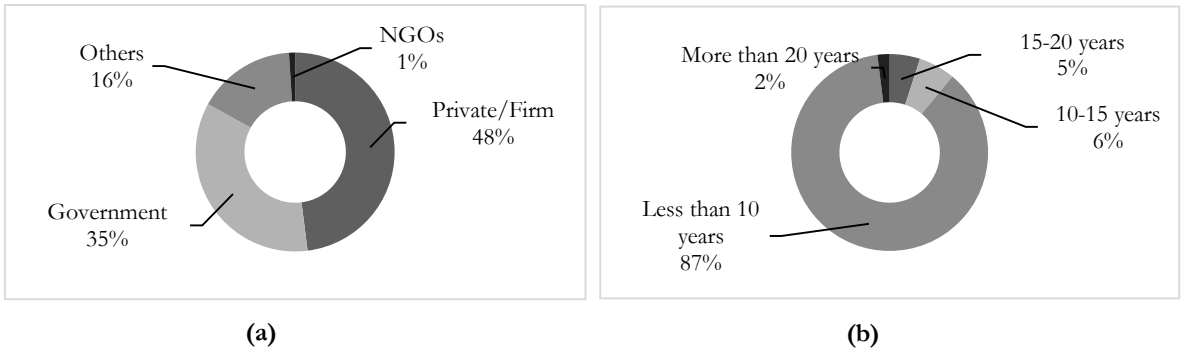

Figure 2. (**a**) Q1- Working organization/company of the respondents; (**b**) Q2- Working experiences of the respondents.

In addition, Bhutan has relatively young working professionals (less than 10 years) which accounts for 87% while only 2% make up for the work experience above 20 years (Figure 2b). That settles 6% and 5% only for the middle career professionals consisting of work experience 10-15 years and 15-20 years respectively.

On the question posed regarding the dilution of the traditional architectural practices (Figure 3a) due to the import of modern materials, methods and laborers, 62% of the respondents agreed in contrast to 38% who disagreed.

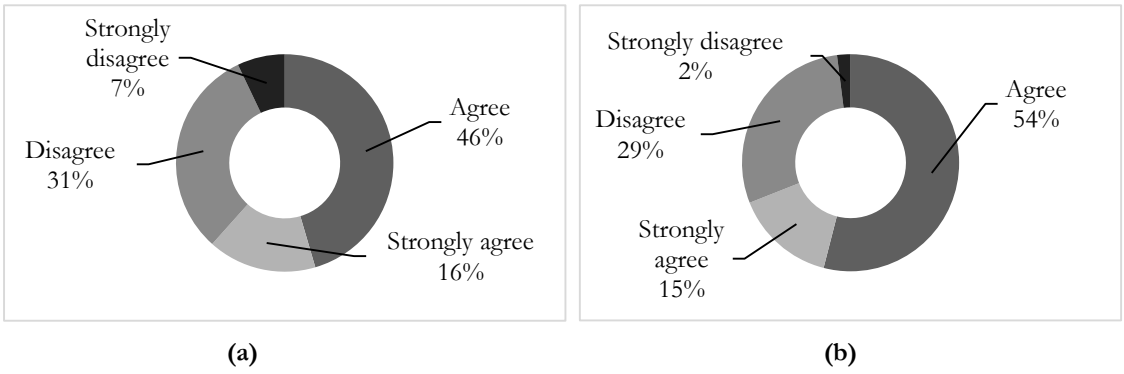

Figure 3. (**a**) Q3- Dilution of traditional architecture due to modernization; (**b**) Q4- Ambiguity in the traditional building style and practices due to new materials and methods

Similarly, the majority of the survey participants (69%, Figure 3b) are in favor of the ambiguity being caused to the traditional building entitlement owing to the adoption of new materials and methods. Meanwhile, 31% of them disagree with the same.

The majority of the participants indicated (Figure 4a) that they are well-versed with the BAG 2014 (65%-average, 29%-above average), indicating only a small minority of 6% whose understanding is below average. Subsequently, when asked about the ambiguity faced/noticed

while using the guideline, nearly 78% of them were in favor of the agreement, but some have voiced their disagreement (22%) with the statement.

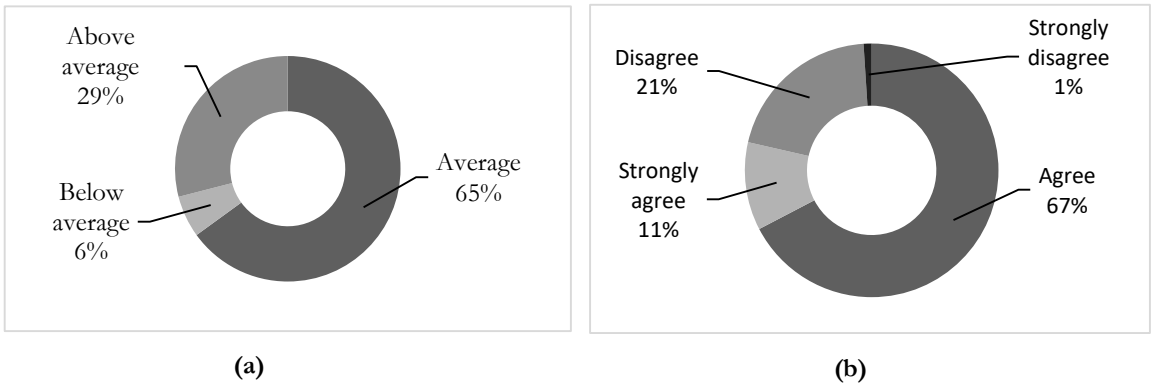

Figure 4. (**a**) Q5- Familiarity of BAG 2014; (**b**) Q6- Ambiguity faced/noticed in BAG 2014

Staggering 88% of them approve the harmonious relationship of BAG 2014 with the traditional architecture design and approach (Figure 5a). In addition, as pointed out by Figure 5b, 75% agree on the positive transformation brought by the institution of the BAG 2014 to the built environment of Bhutan while about 25% of them seem to disregard it.

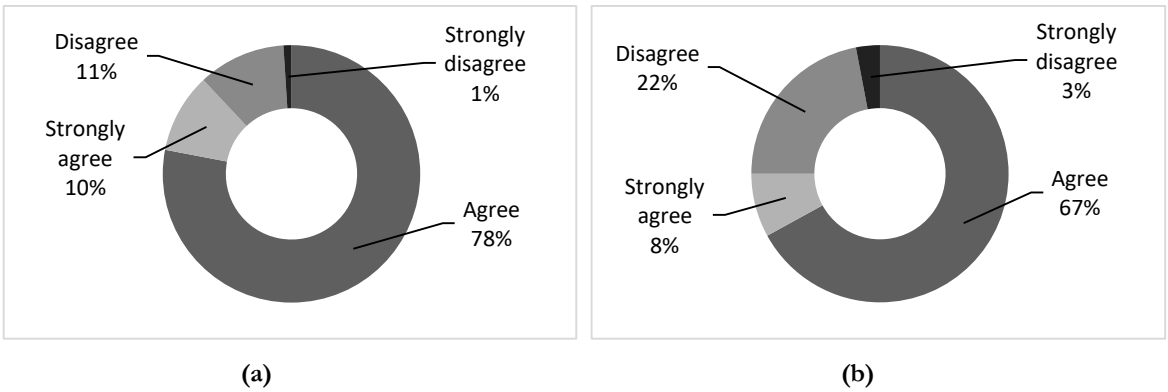

Figure 5. (**a**) Q7- BAG 2014 on harmony with traditional architecture design and proportion; (**b**) Q8- BAG 2014 on positive transformation in Bhutan.

As evident in Figure 6, 87% of the architects vouch for the review of the existing BAG 2014, possibly revealing a strong urge for the review as it was published back in 2014.

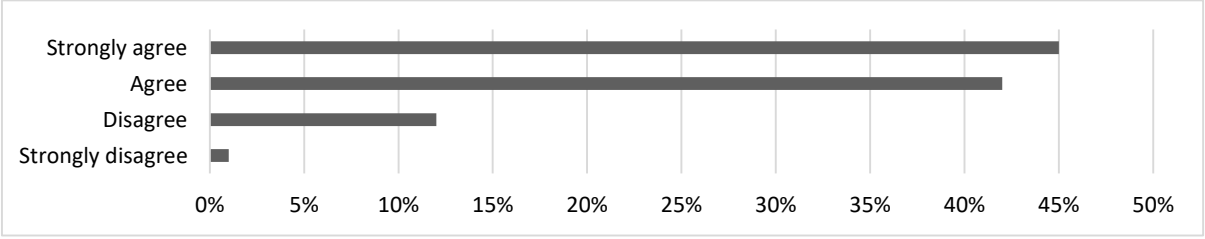

Figure 6. Q10- Need for the review of the guideline.

Lastly, the survey respondents were asked to provide recommendations to be incorporated in the next possible review of the guideline. Out of 100 respondents, only 50 have provided comments in the response section, out of which 8 of them are deemed irrelevant as they are mostly single text or incomprehensible responses. Hence, 42 valid responses are sorted out under the following categories in figure 7.

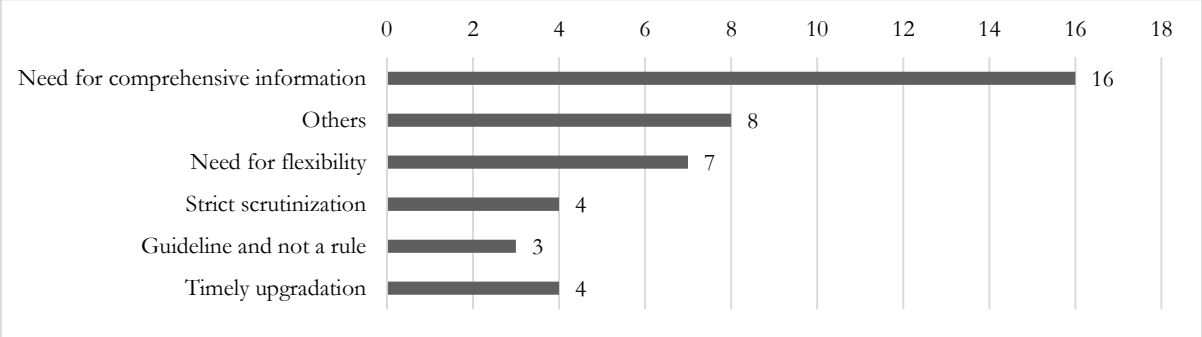

Figure 7. Q10- Categories of the responses with frequency

Results from the visual survey

The visual survey was carried out at the two western districts of Thimphu (32) and Paro (18) which have experienced booming construction activities since Bhutan's exposure to the outside world. The buildings surveyed were categorized under the following:

- Buildings before 1993 (Buildings that came before the publication of the first-ever reference on traditional architecture).
- Buildings after 1993 (Buildings that came after the publication of the Traditional Architecture and subsequently the first-ever Traditional Architecture Guideline in 2002 and followed by the latest revision in 2014 as BAG)

Table 1. Survey details

Location	Timeline	Number of buildings
Paro	Buildings before 1993	7
	Buildings after 1993	11
Thimphu	Buildings before 1993	12
	Buildings after 1993	16
	Total	**46**

The survey is targeted only on the residential buildings and more specifically on the building component, *rabsel* (Bhutanese bay window).

The houses built before 1993 mostly represent typical examples of traditional houses. It exhibits the styles that avoided most decorative/intricate elements such *as zhu, norbu bagam* and even *phana* which required skillful craftsmanship. The majority of these houses are load-bearing structures, constructed by *zowpoens* (master carpenter) using traditional building materials such as timber, stone and rammed earth. In addition, they showcase the true proportion of *rabsel* and cornices and are in accordance with the traditional guidelines.

Out of 19 buildings built before 1993, 14 of them depicted the true size and proportion of the *rabsel* and other remaining 5 of them had slight variations. However, in the case of buildings that came after the institution of the guidelines, the majority of the buildings (16 out of 27) deviated from the traditional requirement of the *rabsel* and the issues are summarized in Table 2.

Table 2. Building deviating the requirements of the Bhutanese Architecture Guidelines, 2014

Sl No.	House No.	Remarks/Inferences
1	House 5a	Side elevation of the *rabsel* is not appropriate
2	House 12a	*Kachen* and *zhu,* not inappropriate size and entitlement
3	House 13a	*Bogh* present in the *rabsel* window
4	House 14a	*Bogh* present in the *rabsel* window
5	House 15a	Minimal traditional features, the correct order of entitlement missing in the cornices
6	House 18a	Minimal traditional features
7	House no.13	Minimal traditional features
8	House no.14	Habitable space above the *phana*
9	House no.15	Minimal traditional features
10	House no.16	*Bogh* is not appropriate in size and proportion
11	House no.17	Window *Bogh* is not appropriate in size and proportion
12	House no. 18	Minimal traditional features
13	House no.20	Problem with the overall proportion of the cornice,
14	House no. 21	*Bogh* not appropriate in size and proportion, *Bogh* present in the *rabsel* window
15	House no.22	*Kachen* and *zhu* not appropriate,
16	House no.25	*Bogh* present in the *rabsel* window cornice not appropriate
17	House 28	Window *Bogh* is not appropriate in size and proportion

Buildings that came before the guidelines are proportionate and are in line with the traditional features. Even the traditional buildings that are built in recent times are proportionate and align with the traditional entitlement of Bhutanese architecture. However, modern buildings that are built using new materials depict varying degrees of interpretation of the traditional

architectural features, conflicting with the BAG 2014. For an instance, in most buildings, *Bogh (cornice)* is not appropriate in size and proportion.

Discussion

The survey respondents indicate that the country has a balanced pool of workforce in private (48%) and governmental institutions (35%). Due to the upsurge in architect graduates, the number in the private sector is only going to increase in the coming years as a very small number of people are being absorbed in government jobs. In addition, Bhutan has relatively young working professionals (less than 10 years) which accounts for about 90%, indicating that the majority of them underwent studies in the early 2000s.

Since the dawn of modernization in the late 20th century (Thinley & Chimi, 2020), Bhutan's construction industry has been faced with the import of modern materials, labor and construction technologies (Department of Urban Development and Housing, 2002). To this, more than half (61%) of the architects agree on the dilution of traditional architectural practices with the import of modern materials, labor and construction technologies and thus providing a broader perspective to the already debated issue (Nima, 2017). Similarly, the majority of the survey participants (69%) are in favor of the ambiguity being caused to the traditional building entitlement owing to the adoption of new materials and methods. This could explain the majority of them (78%) facing ambiguity while using the guideline as well. This is being validated by the visual survey, in which the majority of the buildings of recent times, built using modern materials depict varying degrees of interpretation of the traditional features, conflicting with the BAG 2014. Surprisingly though, traditional buildings of recent times built using conventional traditional materials are still proportionate and align with the traditional entitlement of Bhutanese architecture.

The visual survey also revealed significant numbers of buildings that came after the institution of the guideline not in accordance with the traditional entitlement and proportion, portraying superficial treatment of the façade. This could be due to the ambiguity in the traditional practice as a result of varied materials, techniques and foreign laborers as reflected in the online questionnaire. Few explanations can also be derived from the open-ended responses wherein one participant has said, "Most of the time the traditional Bhutanese architecture is just on the drawing and not on the building." Likewise, it could be due to nearly 10% of the additional cost (Dorji, 2015) incurred by the mandatory traditional features.

Despite the differences in the guidelines, it is astounding that 88% of them agree with the harmonious relationship between BAG 2014 and the characteristics of traditional buildings, and many (75%) agree with the positive outcomes to the built environment of Bhutan resulting from

the establishment of the guideline. Nevertheless, due to the evolution in the construction industry, a stunning 87% of respondents support the need to modify the existing BAG 2014.

The following section of the discussion provides interpretation to the recommendation provided for the possible review of the guideline by the respondents which are grouped under six categories as presented under the result section of this study. In category one, many voiced the need for a more comprehensive and unequivocal guideline that would include more detailed information regarding the Bhutanese architecture, more sections to the existing guideline as demanded by the changing times and lastly on the interpretation of the contemporary Bhutanese architecture. Regarding the need for a more elaborate Bhutanese architecture, although there are few publications on Bhutanese architecture, there isn't an all-encompassing document that brings about not only the tangible architecture but also the rich intangible architecture associated with the traditional features. By bringing, experienced *zowpoens* from diverse regions onboard during the documentation process could serve the aforesaid purpose.

Categories three and four present contrasting ideas. While category three opined about the relaxation to the restriction posed due to the inclusion of mandatory traditional features, a nearly equal number of participants points out that the BAG 2014 is just a "guideline" and not an act or "rule" which must be strictly followed. It was formulated as exposure to Bhutanese architecture and doesn't provide a full manual to practice architecture in Bhutan. In this line, although the Ministry of Works and Human Settlement (2014) points out that the guideline is advisory, it has statutory rights vested by the regulations such as Bhutan Building Rules (2018) and Development Control Regulation (2016) of Thimphu. This should possibly explain the misinterpretation of the status of the guideline amongst the respondents.

The flexibility in the guidelines would enhance the blissful blending of traditional architecture with modern ideas, at the same time not limiting creativity and not compromising on the pristine architectural heritage of the country. Conventionally, the building regulations have a strong correlation with the positive benefits and they should be reasonably rigid and adequately flexible (Nagpure et al., 2016).

Conclusion and recommendations

It can be concluded that the institution of the architecture guideline has aligned new construction activities with the traditional architecture requirements in its pursuit to preserve rich tangible traditional architecture. However, owing to the availability of new materials, techniques and laborers, conventional traditional timber features are translated into modern ways, often failing to justify the traditional requirements leading to superficial facade treatment. Likewise, the

aforementioned factors are also causing ambiguity in the traditional architectural practices and simultaneously in the existing Bhutanese Architecture Guideline 2014.

Despite discrepancies in the guideline, amazingly 88% of them approve of the harmonious relationship of BAG 2014 with traditional architectural features and many agree (75%) on the positive impact brought about by the institution of the guideline to the built environment of Bhutan. However, owing to the changing dynamics of the construction sector, a staggering 87% of the respondents support the need for the review of the existing BAG 2014.

Bhutan's construction industry is run by relatively young professionals. With the changing times, many recommended the comprehensive review of the guideline. Since the guideline has been vested statutory rights by the Bhutan Building Regulation, it is often required to follow strictly which some feel is a restriction to their design creativity. However, there is a section of people who support the inclusion of mandatory traditional features which would go a long way in preserving the country's prestigious architecture. Nevertheless, it is felt that the marriage of traditional features with modern techniques, giving room for flexibility, at the same time restriction would be a way forward.

Like any other study, this study is also subjected to prospects of biases in responses as the individual emotional feelings might have overshadowed. Further, the study only considers the opinion of architects and thus inclusion of the perspective of other players in the construction industry such as engineers, contractors, planners and *zonpoens* may also provide improved insights to better understand the objective of the study.

This study has attempted to shed light on the more complex situation and thus further detailed investigation and need analysis are recommended to accentuate the comprehensive nature of the regulation that shape the spaces around us.

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Occupation Health and Safety in Construction: A Case Study of Bridge Constructions in Bhutan

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Abstract: This paper presents a case study on standard of Occupational Health and Safety (OHS) regulations administered in bridge constructions in Bhutan. The safety guideline developed by Japanese experts in collaboration with Bridge Division, Department of Roads was taken as basis for the assessment. The case study looked into bridge construction projects at the time of their execution and evaluated construction practices against requirements of the guidelines. Based on the assessment, an overall standard of OHS regulations followed in bridge constructions in Bhutan was determined. Factors which obstruct a more holistic adoption of OHS regulations have been discussed along with ways to overcome them.

Keywords: Occupational Health and Safety, bridge construction, safety guideline

Introduction

Construction-related OHS regulations are in their early stages of development in Bhutan. The Labor and Employment Act was enacted by Ministry of Labor and Human Resources (MoLHR) in 2007 following which, OHS regulations were created in 2009 and then revised in 2012. Despite the initiative, OHS regulation has not been implemented thoroughly due to poor linkage among the stakeholder agencies. This has led to proliferation of hazard-prone construction practices at work sites.

Department of Roads currently has an on-going technical cooperation project with assistance from Japanese International Cooperation Agency (JICA). One of the objectives of the project is to develop OHS guidelines for implementation at bridge construction sites. The guidelines are supplemented by field checklists which help in thorough assessment of safety of site activities.

Methodology

The paper starts with description of OHS guidelines and checklists developed as part of technical cooperation project with JICA. The checklist formed the basis for evaluating the status of OHS regulations followed by Bhutanese contractors in bridge construction works. For the purpose of study, 3 bridge construction projects were chosen which were on-going during the time of study i.e. Dechen Bridge (Thimphu) under Construction Development Corporation Limited

(CDCL) and Dangdung and Yourmung Bridges (Trongsa) under Lamnekha Construction Private Limited. The study was carried out through a comparative approach to not only determine the overall standard of OHS regulations but also to learn about differences in methods adopted by these firms. 11 checklist items that were applicable in these projects were evaluated through site visits during different stages of construction.

Contents of OHS Guidelines and Checklist

The guideline identifies different type of work-related accidents that occur in construction sites:

1) Fall accident

   This type of accident involves the workers falling from heights and succumbing to injuries or fatality. Improper scaffolding, absence of hand rails at high heights, uncovered openings or working without safety harnesses are seen to be some of the causes for such accidents.

2) Falling objects

   These are caused by construction materials which fall due to improper securing when lifted. It can also occur due to improper operations of cranes or other lifting machineries. If machines are kept at heights without proper staging, they can fall and cause injuries to workers.

3) Construction machinery

   Mistakes during operations of construction machineries can cause fatal accidents at sites. Lack of communication between the site workers and operators can also lead to such problems. The machines should be inspected before start of any work and the operators' licenses checked. In order to coordinate better working environment, signal men are deployed in deafening situations.

4) Structural failure

   Some structures such as retaining walls, scaffolding, formworks, etc. which are made prior to the main construction can fail due to design faults and poor workmanship. Landslides may come over excavated slopes due to steep gradients. These can cause large scale injuries to the workers and have adverse cost and time implications on the project.

5) Public accidents

   At sites which are not provided with proper barricades, information boards or signal men, there are high chances of general public getting in close proximity of the construction works and causing unnecessary hindrances and accidents.

The checklist identifies three areas to be looked into for the OHS administration. This document is to be used before the commencement of an activity to ensure there are no risk factors to the workers.

Preparatory item

This section is concerned with checking whether a Safety Plan specific to the site is prepared by the contractor or not. Safety Plan is a document that sets out rules and procedures to be implemented during the execution of a project with the aim to protect the workers from any of the identified work hazards. Along with prevention of work accidents, the document also outlines the procedures for responding to a safety incident, providing emergency medical treatments and following up with post-incident reporting.

A safety plan should consist of the following:

1) Assignment of responsibilities

   It should specify who should be responsible for looking after the safety aspect of a construction project at the site. It should also specify who should replace the responsible person during his absence.

2) Frequency of inspection

   The frequency at which the safety inspection to be carried out at site should be mentioned. It should also designate the person responsible for carrying out the inspection.

3) Medical facilities

   The type of medical facilities that should be available during the working hours at the site should be mentioned along with how the emergency responses should be fetched when accidents occur.

4) Safety equipment

   The list of Personal Protective Equipment (PPE) to be provided to the workers should be provided. It should also specify at what frequency should these equipment be replaced.

5) Dissemination of information

   The workers should be made aware of all the safety protocols that should be followed at the site. Additionally, morning meeting should be conducted daily before the works commence so that the workers fully understand about the activities. The document should mention as to who should be responsible for dissemination of such information.

6) Organization and hygiene

The document should state the type of regular tasks that should be carried out for maintenance of hygiene at the site. Along with that the person responsible should also look after proper storage of tools and equipment at the end of the working hour.

7) Post-incident reporting

   This part specifies the type of reporting that should be documented after the accidents occur at the site.

8) Contract management

   This section describes as to how the contractor will ensure that the safety plans will be carried out and followed at the construction site.

Daily works

This section inspects the safety standards in the daily regular works that are performed at the site. The section looks into three key areas as given below:

1) Morning meeting

   The safety inspector (usually project engineer from employer's side) has to visit the site and see whether morning meetings are conducted every day before the commencing of the daily works. The inspector has to assure that during such meetings, attendance of the workers is confirmed seen if any one of them is under the influence of alcohol. Additionally, it should be confirmed that none of the workers are sick. The workers should then be informed of work schedule for the day and notified about the identified safety risks likely to occur.

2) Safety sign board

   Here, the inspector has to inspect and confirm that the construction site is provided with at least one safety sign board with the message "Safety First". The minimum size of the sign board should be 30cm x 100cm and it should be erected at a point from which it is readily visible across the site.

3) Personal Protective Equipment (PPE)

   The safety inspector has to check whether the workers are equipped with safety gadgets such as safety helmet, boots, working uniform, gloves, safety harnesses (if appropriate), goggles, etc.

Specific works

This section deals with inspection of safety standards in specific works that a particular project will carry out depending on the nature of construction. These have been discussed as:

1) Earthworks

The specifications and conditions of machines (such as backhoe, bulldozer, dump trucks, pay loader, etc.) that will be deployed for the earth works should be checked along with their operators' licenses. Signal men should be properly deployed so that the work is not hindered by general public. The working ground for the machines should be checked so that they do not get into precarious positions during operation.

The gradient of the excavated slope should be checked and reconfirmed prior to the excavation. To prevent the workers from falling rocks, proper barricade should be made and safety helmets provided. If groundwater is found to be present, a proper drainage channel should be provided to flush out the water. In order to haul the excavated matter, a proper access road should be made beforehand.

2) Scaffoldings

The material used for scaffolding should be strong and of standard quality. All the openings should be covered with footboards which should be tied at the ends of strong parts of the scaffolding. At places where the working height is more than 2m, railings of 85cm height are recommended. Safety nets are to be fixed in order to prevent from hazardous activities. Proper ladders should be provided for vertical movement along the scaffolding. They should be tied at the top and provided with slip stoppers at the bottom. Any unnecessary hindrance in the working platform should be removed. When the scaffolding is dismantled, it should be ensured that they are systematically removed in step-wise manner.

3) Concrete works

The inspector should see if the concrete pouring method adopted (manual, chute, concrete pump, etc.) is appropriate for the site. The ground or staging for concrete mixer or transit mixer should have adequate bearing strength so that they do not topple or lose footing during operation. In case of a transit mixer, a signal man should be deployed so that it reaches the site in timely manner and does not get disturbances from general public. The scaffolding used for concreting should be of sound material and have adequate strength.

4) Formworks

The formworks should be prepared in a yard which is spacious and clean. The inspector should check whether or not the formworks conform to their structural design calculations. The materials used should be of sound quality and free from any defects. The scaffolding for the formworks should be of adequate strength to take on the load

that comes on them once the concrete is placed. When the formworks have to be placed at higher heights, proper care should be taken when lifting them up. In case footboards cannot be placed along the scaffolding, the workers should be provided with safety harnesses to prevent fall accidents.

5) Lifting works

The size of the tension wires used for lifting should be of adequate diameter and strength. They should be free of defects. Proper slinging method should be employed so that the lifted object does not swing excessively during lifting. Signal men should be deployed so that he can effectively transfer the message to the operator through visual signals. It should be made sure that the operators and signal men are thorough with various signals that will be used. No workers should be allowed to come under the lifted load.

6) Construction site

The inspector should make sure that the construction area is properly barricaded so as to prevent the entry of general public or other nuisances. The site should be clean with the equipment and material properly organized. Access roads, if any, should be provided with guiding ropes at the edges. There should be construction information boards at appropriate locations so the general public or visitors are aware of the on-going activities.

7) Acetylene and oxygen gas cylinders

These cylinders should be kept standing in storage and provided with fall preventive mechanism. The storage for the cylinders should be maintained at less than 40 degree Celsius ensuring the cylinders are in standing position at all times. The inspector should make sure that the cylinders are kept standing even during the actual use. Any fire related activity should be performed at least at a lead of 5 m from storage.

8) Power supply

A standard power distribution panel boards should be provided with an appropriate specified transmission wire, avoiding any wet area. The connections made should be proper and should be away from wet areas. Proper earthing should be made.

9) Crane and heavy machineries

The capacities of such machines should be checked to ensure that they are adequate for the site requirements. The inspector should also make sure that the machines are regularly inspected and maintained. Signal men should be deployed when such machines are operating.

These are some of the specific works that the checklist covers. The inspecting engineer should visit the site and inspect all of these requirements before approving the activity. In case the contractor fails to meet any of the stipulated requirements in the checklist, the inspector has power to halt the on-going activities based on the observation report until the recommended changes are adopted.

Case Study

The standard of safety regulations implemented at Dechen Bridge construction project executed by CDCL and Dangdung and Yurmung Bridge construction projects executed by Lamnekha Construction Pvt. Ltd. were studied and compared to understand the existing status of OHS in the country. The projects are similar in terms of nature of construction, cost incurred and project duration.

Dechen bridge was completed in 27 months in June 2019 at a cost of Nu. 108 million. The bridge is reinforced concrete arch type of 96m span. Dangdung and Yurmung bridges were completed in 18 months and 12 months respectively. The total cost of the two projects is Nu. 110 million. Both the bridges are 50m long and are of steel truss girder type with concrete decking. The differences between the OHS regulations are as tabulated below:

Table 3: Comparison of Wangchu Zam and Dangdung & Yurmung Zam constructions

Sl.	OHS Aspect	Dechen Bridge	Dangdung & Yurmung Bridges
1	Safety Plan	Not submitted	Not submitted
2	Daily meeting	Conducted where the activities for the day are informed of and attendance taken.	Not conducted
3	Safety sign boards	Safety sign board with visible message was provided at a point which was visible across most of the site.	No safety sign boards were provided.
4	Uniform and PPE	Project Manager, Project Engineer and workers wear appropriate site uniforms along with PPEs such as safety helmets, boots, harnesses, etc.	Although the workers were provided with safety helmets and boots, there were not any site uniforms for them. So, the workers worked in their casual clothes.
5	Scaffoldings	Although sound materials were used for making scaffoldings, they were not designed and checked for safety. Footboards were only provided at certain locations and some openings were left uncovered. Hand rails were not provided at places where the height exceeded 2m. Ladders used for vertical movement along the scaffolding were awkward to walk on.	Similar case.

6	Earthworks	Before the excavation, access route was created so the dump trucks could reach the point of excavation and take away the excavated matter. The excavated matters were properly dumped at designated area.	Proper cut slopes were not maintained. The excavated materials appeared to have been dumped on the downstream side of river.
7	Formworks	Formworks used were clean and of strong material. However, they were not designed and checked for safety.	Similar case.
8	Construction site	The construction site is thoroughly barricaded with CGI sheets to prevent entry to the general public and cause unnecessary hindrance to the work. This also protects public from work accidents that are likely to occur at the site. Construction information boards are provided near the entrance for awareness of the public and visitors alike. However, no such information boards are fixed on the other side of the river, where, owing to their absence, people are often seen driving till the site and going back.	The construction sites were open with no barricades at all. There were no project information boards at the site. The site engineer reasoned that the site was far away from public centers and the adjoining roads were not yet opened to traffic. At Yurmung bridge site, a narrow wooden plank had been laid across the stream as a means of river crossing for the workers. The plank was not properly fixed at the ends and did not have any hand rails as side supports.
9	Acetylene and oxygen gas cylinders	Although the cylinders were stored in shaded areas, they were not kept upright but rested in sideways manner. Even during the actual use, they were kept rested and not upright.	Similar case.
10	Power supply	Proper power distribution panel boards were used along and electric wires used were of appropriate specifications.	Similar case.
11	Shoring works	For shoring works, 4 temporary concrete frames were built on the river bed. Wooden planks were placed across these frames and shoring metal poles raised upon them. Designed shoring arrangement was used with proper metal clamps. Walking platforms were provided by laying wooden planks across the openings. Workers used safety harnesses while working on the structure. However, when dismantling, it was observed that the workers threw the shoring poles carelessly from where they were detached into the flowing water below.	During the launching of steel truss girders, no shoring structure was built to support the girders. Instead, tension steel wires were stretched over the steel towers at each abutment and anchored to heavy weights. The girders were then suspended by means of wires and launched across after fixing the connections. During the launching, the workers were seen without safety helmets and safety harnesses.

(a) **(b)**

Figure 5: Comparison of working conditions between Dangdung Bridge and Dechen Bridge. (a) Workers at launching of steel girders without safety belt and PPEs. (b) Quality check/audit at Dechen Bridge with workers in proper PPEs.

Observations

As it has been observed in this case study, in both construction projects, no safety plan documents were submitted prior to the start of work. There were no safety inspectors deployed by employer to scrutinize the standard of safety regulations implemented at the sites. The construction works carried out at Trongsa exhibited high level of working hazards which were totally ignored. The construction areas were not barricaded and no information boards were provided for public awareness. Workers worked in their casual clothes which are actually not suitable to work in. Safety helmets and boots were reportedly provided but its use during the work was not strictly imposed and as a result many workers could be seen without their safety gadgets during site visits. Even during the launching of the huge steel girders across the river, workers could be seen walking on the suspended girders without any safety harness. The gradient of cut slope was dangerously steep and even the scaffoldings were seen to be erected on weak soils. The practice of conducting morning meetings with the workers before starting the day's work was completely absent.

Dechen bridge construction project in Thimphu did significantly better with regard to administration of OHS. The work yard was barricaded and appropriate information boards were provided. A "Safety First" sign board was also fixed at the site to indicate that safety of the workers is the first priority. Morning meetings were conducted every day before the commencement of the day's work. The workers worked in their proper site uniforms fully equipped with required PPEs.

Some shortcomings were also observed at Wangchu Zam site. For instance, the scaffoldings and formworks should be designed and checked for safety as stipulated in the safety control guideline. The gas cylinders were kept at inappropriate positions in storage as well as in the time of operation. Hand rails were not provided at places where the fall height exceeded 2m. The ladders used for vertical movements were not properly made and posed risks. Dismantling of scaffoldings was not monitored well and workers were seen disposing the detached poles carelessly into the river.

OHS administration should be thorough and encompass all the working hazards that are likely to occur during the course of a work. Even a minor hazard will have the potential to cause high negative impact on the workers. An injury or a death at a site, resulting from a working hazard can lead to impedance of the progress due to post-incident processes. Moreover, such negligence can lead to premature failing of structures even at construction stage and cause injuries and deaths on large scale. This will have huge undesired financial implications on the cost of the project. Therefore, OHS administration should be thoroughly comprehensive and encompassing in order to provide a safe working environment for the workers involved.

Results

OHS administration has failed to gain momentum in the past decade despite the enactment of Labor and Employment Act in 2007 by MoLHR and subsequent formulation of OHS Regulations in 2009 and 2012. In line with observations of the case study, following factors can be attributed to this:

1) Lack of specialized expertise in the field of OHS and poor coordination between the policy makers and implementing agencies.
2) Lack of awareness among contractors and workers. In absence of proper information, workers and contractors are unaware of PPEs and safety measures that can be adopted at work sites for prevention of hazards. This is further aggravated by low literacy level among workers.
3) Today, none of the contract documents used as guiding entity for construction works in the country has any definite clause persisting on proper administration of OHS and

imposing relevant penalties upon failing to do so. Although some contracts spell out the use of PPEs by the workers at site, the absence of any legal implications on the failure of its adoption has led to its negligence in most cases.

Conclusion

The administration of OHS has a long way to go from where it stands today. After an unremarkable decade marked with failure to gain momentum despite enactment of law and framing of regulations, it is high time that the relevant agencies collaborate and formulate rules to be implemented across the concerned sectors. Proper designation of responsibilities to the agencies and framing clear cut policies and regulations can help streamline the administration and also eliminate unnecessary duplication of works.

The resulting rules should have legal-binding provisions that will facilitate strict implementation by the executing entities. For instance, in the construction sector, the contract documents should have appropriate clauses calling for thorough administration of OHS at work site to promote a safe working environment not just for the workers but also for the general public who may get involved indirectly with the work. The clause can also specify the list of penalties to be imposed upon the contractor when he fails to uphold the clause and performs an activity under hazardous conditions.

Expertise in the OHS should be developed by providing opportunities for specialization in the field and training in relevant programs. Data collection associated with working hazards should be taken up by a related agency and researches conducted to develop more appropriate measures. Further studies can be conducted to develop ways for incorporation of the safety guidelines presented in this paper in other types of construction works such as roads and buildings.

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Structural and Cost Comparative Analysis of RC Framed Building by Using Various Infill Wall Materials

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Abstract: The constant increase in the cost of building material has led to consider a cost saving alternative which can make the cost of construction affordable for the respective stakeholders. With government economic policy inclined towards the use of locally available materials in construction sectors, the need to substitute conventional infill wall materials like red clay brick, which is largely imported, with concrete bricks and autoclaved aerated concrete (AAC) blocks has made the stakeholders indecisive due to its indefinite financial impact on the project cost and the variance in structural performance of the building. This paper investigates potential economy achieved by using different infill wall materials of mandatory thickness on a specified building and studies the influence of the infill wall on the structural performance of the building by comparing the structural parameters like the story drift, displacement, base shear, story shear, building moment & shear force. From the structural analysis performed it has shown that the building with AAC infill wall was better compared to the other two. In terms of cost savings, the overall cost of the building with AAC infill wall was economical by 5.6% and 6.2% compared to red brick and concrete brick respectively.

Keywords: Cost saving, Structural load, infill wall material, red clay brick, Solid Concrete brick, AAC block.

Introduction

Cost benefit analysis is a systematic approach to estimating the strengths and weakness of alternatives used to determine options which provide the best approach to achieving benefits while preserving savings. It is important that we select the best building infill wall materials since it has significant impact on the overall cost of the project with additional factors like cost effectiveness, labor requirements, technical skills, weathering actions, environmental issues and energy efficiency playing a part in the selection of the building infill wall material.

The rapid growth in technology and continuous innovations has led to coming up of many new building wall materials, ranging from traditional and naturally available materials to artificially manufactured materials like red clay brick, autoclaved aerated concrete (AAC) blocks and solid concrete block. With the availability of more choices in the market, the people are unaware and indecisive of choosing the better infill wall material for their building. In this regard, this study

aims to benefit those people in their decision-making process to opt for better infill wall material by evaluating the structural performance of the building and by comparing the cost incurred by using different wall materials.

The wall materials taken into considerations for the study are red clay brick, AACblocks and solid concrete block. The reason for choosing the aforementioned materials for this study is because these materials are being commonly used in Bhutan and are readily available in the market.

Red bricks are made of clay which is eco-friendly and doesn't catch fire easily. Red brick walls are heavy and quite expensive. Concrete blocks are very strong and durable. They don't require maintenance too often and installation of concrete block wall is not much labour intensive. Autoclaved aerated concrete is an eco-friendly and certified green building material which is lightweight, load-bearing, high-insulating, durable building block.

Infill walls are termed as the non-structural element hence no design standards are in place. However, the infill walls do play a part in the seismic behavior of the building in the case of lateral loading. The masonry infill walls may have significant effects on the seismic response of the reinforced concrete frame structures; therefore, infill walls need to be considered during the design and analysis of the building (A Ahmed, 2018).

The AAC blocks infilled RC frame exhibits better performance subjected to lateral loads than that of conventional bricks infilled frames. The decrease in the storey shear in AAC block masonry is found 35% as compared to red brick infilled masonry (Nayakar, 2018). The low strength and stiffness of AAC infill results in improved load sharing between infill and frame, which help to develop yield mechanism in the frame earlier for better energy dissipation (Supratik Bose, 2014).

The usage of AAC block reduces the cost of construction up to 25% as reduction of dead load of wall on beam makes it comparatively lighter members. The use of AAC block also reduces the requirement of material such as cement and sand up to 55% (Alim Shaikh, 2013). AAC block reduces operation cost by 30% -40%, reduces the overall construction cost by 2.5% as it requires less jointing and reduces the need for cement and steel. AAC reduces construction time by 20%. The productivity of mason with AAC block increases up to 3 times due to a smaller number of joints (Shukla, 2014).

Materials and Methods

For this study, the building taken into consideration is a typical residential G+4, Category III quarter for the proposed affordable housing project to be constructed by NHDCL with the

support of ADB (ADB, 2020). Separate analysis was carried out for the specified building with different infill wall material. Design optimization were carried out as per the obtained analysis results from the Midas Gen V2021 software for the structural components of the building like their beam, column and footing sizes. The design coefficient of 0.8 were kept constant for all the design. The reinforcements were distributed as per the optimized design and the cost comparative analysis were carried out by using BSR 2020.

The design and analysis for the G+4 Structure was carried out using the design software Midas Gen V2021. The reinforcement values for the beams were calculated considering the area of steel values from the software. For the column, capacity design was used to obtain the reinforcement values as per IS 13920, 2002. In the case of footing design, the critical reaction value was obtained from the software and further design was carried out using IS 456, 2000.

For the estimation and costing, (BSR, 2021) was used to find the rates for specific items and when the rates for items are not included in the (BSR, 2021), the combination of (LMC, 2021) and (BSR, 2021) were used to find the Labour/Material Coefficients and Basic Material/Labour Rates respectively, and also the prevailing market rate to do the Rate Analysis. The prevailing Market Rates are used when the rates are not included in Basic Material and Labour Rates in (BSR, 2021).

Results and Discussion

This research includes findings in terms of structural performance of the building & cost benefit analysis for the different building wall material:

Structural Performance of a Moment Resisting Framed Building

The structural performance of the building is compared among the three infill wall materials using the structural parameters such as the base shear, story displacement, beam moment and the stiffness irregularity check.

4) Base Shear

Base shear is an estimate of the maximum projected lateral force on the base of the structure due to seismic activity.

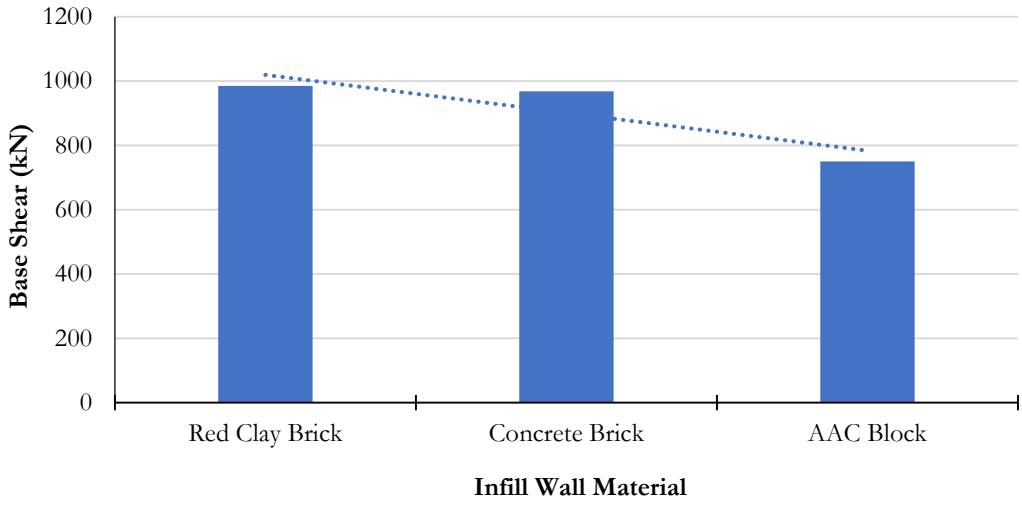


Figure 6. Base Shear of Building with different infill wall materials

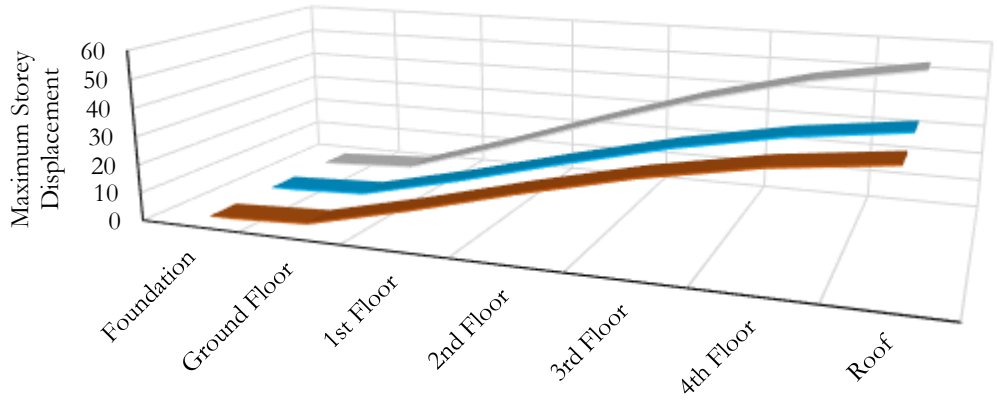
The base shear of the building with AAC block masonry is less compared to the other two. There is a decrease in the base shear of the AAC in filled wall building by 23.87% compared to the conventional red clay brick and 22.53% compared to Solid concrete block. This is because of the light weight of the AAC block contributing to the dead load of the building. Due to the reduction in the base shear, member forces are also reduced which leads to the reduction in the percentage of steel & sectional sizes of the structural components of the building.

5) Storey Displacement

Storey displacement is the lateral displacement of the story relative to the base. The lateral force-resisting system can limit the excessive lateral displacement of the building. The story drift is the relative displacement of one-story relative to the other. The importance of the story drift is in the design of partitions and curtain walls.

The role of the infilled wall material contributes to the stiffness of the building which is normally determined by the designing through equivalent diagonal strut modeling of the infill wall. However, in our study & going by the common practices of building structural design in Bhutan, we don't design the infilled wall material through the equivalent diagonal strut method. Our common practice is to apply the weight of the wall on the external & internal beam which doesn't consider the infill wall as a part of the lateral force resisting system. As per the study by (A Ahmed, 2018), it is concluded that building analysis and design with infill walls can economize the cost of structures as the in-fill walls contribute towards lateral stiffness due to braced frame action.

The maximum displacement obtained for the red clay and concrete brick masonry building is 40.36 mm and 41.00 mm in the lateral Y direction. In the case of the AAC block masonry building, the maximum value 53.55 mm in the lateral Y direction. Since our scope of study does not consider the lateral stiffness contributed by the infill wall in the building, the story displacement is only due to the structural loading of the building. Owing to the lighter building material in the case of AAC masonry building, the story displacement is found to be the highest among the three buildings. The stiffness contributed by the overall weight of the building which helps to resist the lateral forces is highest for the red clay brick masonry building resulting into the least displacement among the three.



	Foundation	Ground Floor	1st Floor	2nd Floor	3rd Floor	4th Floor	Roof
Red Clay Brick	0	1.65	10.42	20.15	29	35.9	40.36
Concrete Brick	0	1.63	10.32	20.06	29.09	36.27	41
AAC Block	0	1.94	13.61	26.2	37.89	47.36	53.55

Figure 7. Maximum storey displacement of building with different infill wall materials

6) Bending Moment

The most common structural element that is subjected to bending moment is the beam, which may bend when loaded at any point along its length. The stiffer the building, higher the moments are developed in the structural element of the building to resist the lateral forces thus requiring higher sectional member sizes and high percentage of reinforcement.

Consequently, the building with the red clay brick which had higher stiffness values was observed to have developed higher moments in the structural elements eventually

resulting into higher reinforcement values. As shown in the table 1 the highest beam hogging and sagging moments of 145.7kN-m and 76.3kN-m respectively of AAC blocks is still lower than that of the red clay bricks and solid concrete blocks thereby resulting in the economy in terms of reinforcement quantity.

Table 4. Critical Hogging & Sagging bending moments

Storey	Beam Hogging Moments (kN-m)			Beam Sagging Moments (kN-m)		
	Red Clay Brick	AAC block	Solid Concrete Block	Red Clay Brick	AAC block	Solid Concrete Block
6	-71.5	-77	-73.5	28.09	33.4	28.1
5	-123.9	-112.8	-122.5	44.81	43.6	48.8
4	-148.8	-134.8	-146.6	67.41	65.7	73.1
3	-162.9	-145.7	-159.1	81.09	76.3	85.1
2	-161.7	-145.6	-156.3	80.47	76	82.8
1	-79.8	-73.7	-80.3	44.70	47.2	43.2

Cost Comparative Analysis of AAC blocks, Red Clay Bricks and Solid Concrete Blocks.

7) Infill Wall Saving

After carrying out the detailed study and estimation of G+4 building using three different infill wall material, total project cost savings is determined in terms of infill wall saving, plaster saving, maintenance cost saving, labour cost saving and reinforcement saving.

Table 5. Estimated cost for 1 cum of infill wall

Sl. No.	Material	Unit Cost (Nu.)	Quantity per cum	Total Cost (Nu.)
1.	Red Clay Brick	13.00	650.00	8,450.00
2.	Solid Concrete Block	8.15	18,800.00	153,163.60
3.	AAC Block	12.00	504.00	6,049.15

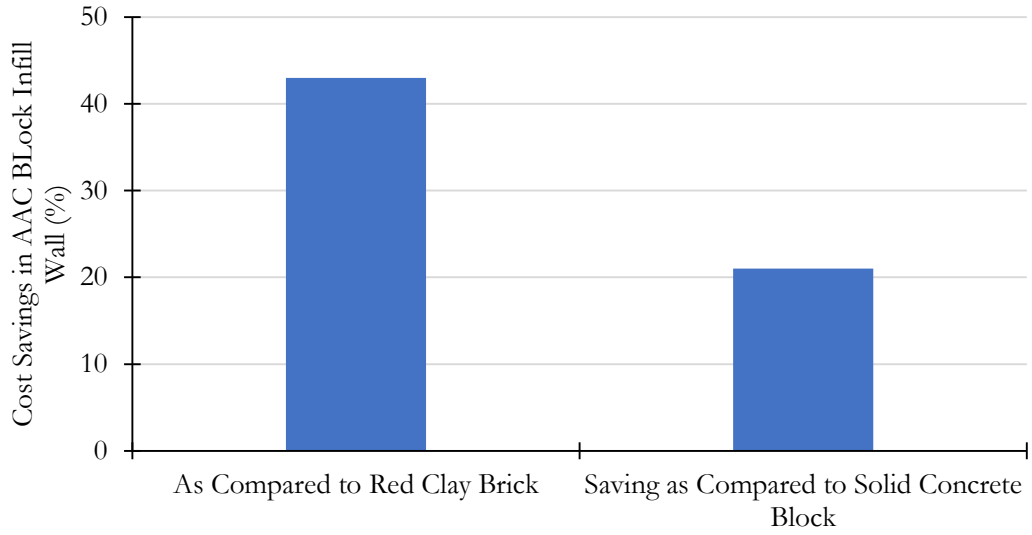


Figure 8: Cost Savings in AAC Block Infill Wall.

8) Plaster Saving

AAC blocks have uniform shape and texture, which gives even surface to the walls. The AAC block when built has both faces as fair faces as compared to brick work which has only one fair face and has undulations at the same time. Hence, the thickness of plaster for AAC block is much less compared to conventional bricks.

The thickness of plaster used in this estimation is 6mm for both internal and external walls for AAC Blocks as infill material in compliance with BSR 2021. For red clay bricks & solid concrete blocks, the plaster thickness considered is 12mm for internal wall and 15 mm for external wall. There is 21% saving in plaster while using AAC block as infill wall material.

Table 6. Cost difference in plaster works.

Description	Red Clay Brick	Solid Concrete Block	AAC Block	Cost Saving
Cost of Plastering (Nu)	828,836.60	828,836.60	656,663.30	21% saving in AAC block as infill material

9) Maintenance Saving

For maintenance cost saving, considering the life expectancy of a building to be 50 years and keeping the maintenance requirement of the infill wall constant for a periodic cycle 10 years the use of AAC block reduces the operating and maintenance cost in terms of plaster by 21% as AAC comes in precise and accurate dimensions unlike red clay bricks and so the AAC blocks after laying offers a uniform surface without any undulation.

So, a thin layer of plaster is also sufficient to plaster the wall. wall painting and plaster last longer as there is minimal efflorescence effect on AAC. Moreover, AAC blocks are characterized by micro pores. Micro pores are small air bubbles evenly distributed throughout the material which restricts the entry of water molecules. As such, absorption of water into the AAC material is minimum. This translates to lower maintenance cost for AAC blocks and increased durability.

10) Labour Cost Saving

The table below depicts the amount of work done represented by the number of days required by each worker to complete 1 cum of infill wall which is relative to the labour cost savings.

Table 7. Estimation of labour cost for 1 cum of infill wall

Infill Wall Materials	**Mason Gd.1 Days**			**Mason Gd.2 Days**			**Labour Days**			**Labour Cost**	**Cost Saving**
	Days	**Rate (Nu/ Day)**	**Total Cost (Nu)**	**Days**	**Rate (Nu/ Day)**	**Total Cost (Nu)**	**Days**	**Rate (Nu/ Day)**	**Total Cost (Nu)**		
Red Clay Brick	0.763	632.5	482.5	0.763	575	438.7	2.792	460	1078.2	1,999.542	51% in AAC compared to the conventional brick.
Solid Concrete Block	0.763	632.5	482.5	0.763	575	438.7	2.792	460	1078.2	1,999.542	
AAC Block	0.431	632.5	272.3	0.431	575	247.6	1.019	460	468.5	988.506	

LMC 2021 and BSR 2021 were used for the calculation of labour days and rate respectively. Using the LMC 2021, the labour days for the construction of the building were calculated by multiplying the coefficient of specific workers with the total volume of the infill wall materials required. The labour days were then multiplied with the rates from BSR 2021 to find the total cost of specific workers. There is up to 51% saving in cost of labour in terms of AAC block as infill wall material due to bigger size and lighter weight of AAC block which translates to a smaller number of blocks in wall work. The lesser joints in AAC also contributes to 3 times reduction in time required to lay the blocks.

11) Reinforcement Saving

Due to the changes made in the building wall material, changes were observed in the values of the reinforcements in beam, column and the footing. The steel take-off in structure with AAC block reduced by 32.86% compared to red clay brick and 30.14% compared to solid concrete block. The steel take-off in the beams for AAC block structure is lower compared to solid concrete block by 45.8% and 44.13% compared to red clay brick.

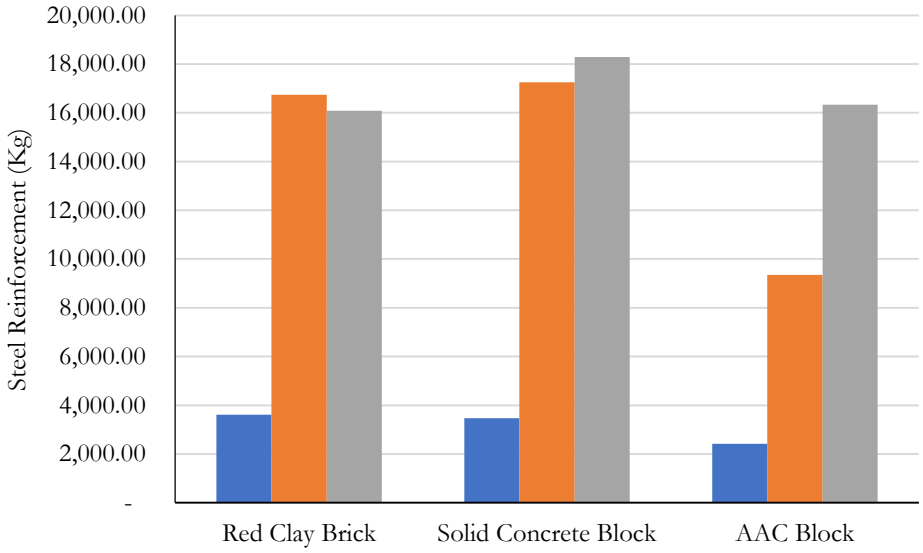


Figure 9. Steel quantity take-off for structural members

Total Project Cost Comparison

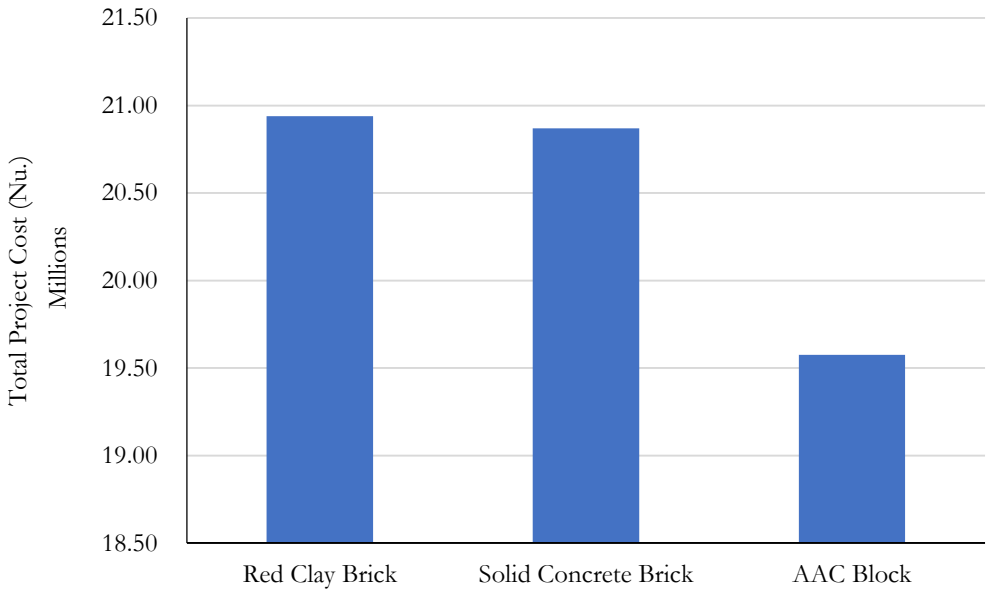


Figure 10. Total project cost of the building

AAC blocks are more cost efficient than red clay brick and solid concrete blocks**.** There is reduction in overall construction costs by 5.6-6.2% as compared to red clay brick and solid concrete block respectively, as it requires less jointing, lesser excavation for foundation and reduces need for cement, sand and steel. The thickness of plaster is also reduced up to 50% which further reduces the cost of construction. The micro pores characterized in AAC block restricts the entry of moisture which keeps detoriation and maintenance minimum in wall plaster hence reducing maintenance cost as well.

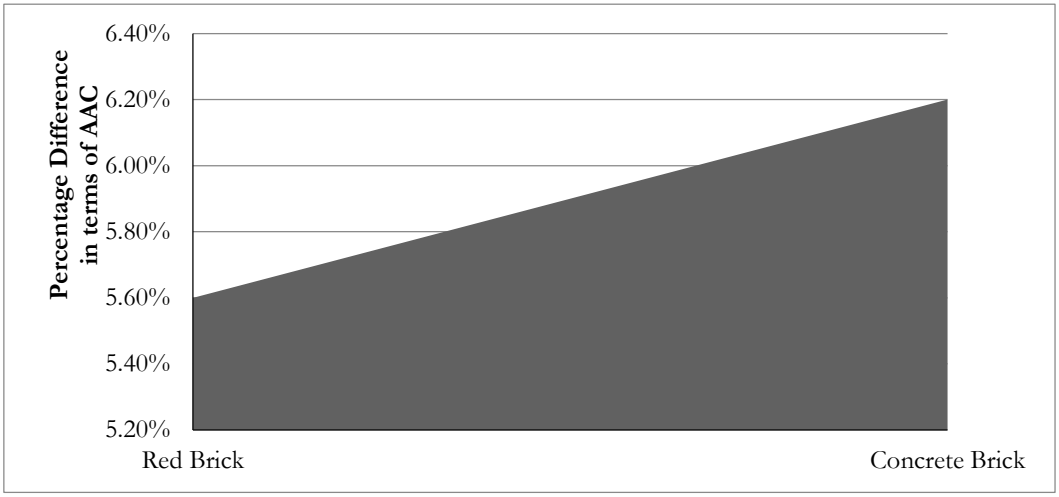


Figure 11. Percentage cost saving for the overall project cost

Conclusion and Recommendations

In our study, an effort has been made to understand the difference in the building's structural behavior and the cost incurred by the use of three different types of infill wall (i.e., red clay brick, solid concrete brick & AAC block) materials available in Bhutan. The lightweight nature of the AAC block has significant impact on reducing the building dead load, resulting into the reduction of the structural member section size and reinforcement percentage. The reduced base shear and moment benefits the structure to perform better during seismic loading. Thus, from this research it can be concluded that the AAC block infill wall achieved better level of structural stability as compared to red clay brick and solid concrete brick.

From the cost comparative study, it was found that the cost savings achieved from our study by comparing AAC block with conventional red clay brick and solid concrete brick was 5.60% and 6.20% respectively, which would not result in substantial amount due to the accompanying materials to be used and the cost incurred with different sites. The building components affected by the type of infill wall, was studied based on their altering cost of materials. The alteration caused by the infill wall types on the plastering cost, labour cost, maintenance cost and reinforcement

cost, favored more saving in the AAC infill wall as compared to conventional infill walls. The varying demand and availability of the infill wall material significantly influences the rate and maybe subjected to change against our study.

As a common building design practice in Bhutan, infill wall is considered as a non-structural member which does not play the role of lateral load resisting member. Thereby the study of our research is limited to the understand the actual behavior of the building contributed by the type of infill wall used in the building and the limiting subject will be the future scope of study

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Conflict of interest: The authors declare no conflict of interest.

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The Conceptual Analysis of Occupational Health and Safety in ConstructionIndustry of the Tsirang Dzongkhag

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Abstract: The Occupational Health and Safety in the construction industry has drawn their place, in the spheres of researchers given its paramount importance for the wellbeing of the parties involved. The study on the conceptual analysis of Occupational Health and Safety (OHS) in the construction industry was explored on the conceptualization and implementation by contractors, employees, and engineers of the Tsirang Dzongkhag. In total, 14 contractors, 19 engineers, and 71 employees (n=104) were administered in the study. The quantitative research method and a five-pointed Likert-scale of item survey questionnaires were enforced. The data were analyzed using Statistical Package for the Social Science (SPSS of version 22) to compare means and standard deviation. The means (M=3.7 & M=3.8) respectively was resulted in the engineers and employees findings of agreed. However, the contactors mean (M=3.5) was shown as neutral in the findings. The contractors were revealed in elasticity mode about the health and safety of the employees in the construction industry. To overcome uniformity observation, the study can be apprised for the rest of the dzongkhag for a future researcher.

Keywords: Health, Safety, Implementation, Perception, Construction Industry, Enforcement

Introduction

The OHS is mainly intended for the well-being of the employee on-site, to have larger benefits of basic rights of the employee, which can aid themselves and their families. The International Employee Organization (ILO) and World Health Organization (WHO) jointly adopted Occupational Health and Safety in 1950 and later revised in 1995. Revering to ILO and WHO, more than two million annual work-related deaths are rising due to rapid industrialization in developing countries. Besides, each year about 268 million non-fatal workplace accidents are resulting in at least three days of absence from work. However, in Bhutan, the Occupational Health and Safety (OHS) regulation inthe construction industry in Bhutan was quite low in the past decade (Dorji, 2006), despite the enforcement of the Labor and employment act of Bhutan, 2007, and regulation of welfare (WHO & MOHLR, 2012).

To figure out on the ground reality, the concept of OHS in the construction industry was amended. The depth of OHS was broadly focused on the highest degree of the physical, mental,

and social well-being of employees in all professions to have smooth workmanship as a wage earner. According to the Department of Labor and WHO, Bhutan Office (2012), The OHS plays a vital role in the safety of the employee in the construction industry, the use of Personal Protective Equipment (PPE), Common Protection Measures (CPM), and Life Insurance are mandated. Additionally, the Ministry of Labor and Human Resources is enforced particularly on the prevention, enforcement, and compensation of the employee. The implementation and gaining compliance with the OHS provisions which include the standards of OHS are even conferred with the Ministry of Health organization about the Labor and Employment Act, 2007.

In the growth of urbanization and modernization in construction technologies, employee health hazards need to fast prioritize. The contractors and procuring agency has to reserve the life insurance of the employee as a safety factor. The purpose of this study is mainly intended to determine the standard of OHS in the Tsirang Dzongkhag, Bhutan, by using the quantitative method. The data was collected through a survey questionnaire from the contractors, engineers, and employees.

Literature Review

Importance of OHS

The construction industry in Bhutan is one of the fastest-growing and largest sectors. It is also one of the highest contributing sectors to the national gross domestic product (GDP) next to agriculture. However, occupational safety and health in the construction industry in Bhutan is at the very basic leve (Dorji, 2006). The successful completion results of the project are the best reward for implementing the quality, cost, and participant satisfaction of the OHS in the construction site (Ashley, 1987). Similarly, Chan et al. (2002) also defined that construction project success as the degree of project goals and expectations that are met on time. The strong determination of the contractor on the use of OHS can save the employee's life from a fatal accident at the construction site. The implementation and gaining compliance with the OHS provisions which include the standards of OHS are even conferred with the Ministry of Health organization about the Labor and Employment Act, 2007.

Perceptions of OHS

The sense of accountability for OHS needs to grow green in the minds of the contractor, to have potential benefits for the employee at the workplace. Further, the implementation of the OHS needs to be graded by the respective engineers, Procuring Agency, and the Department of Labor for the safety of the employee on site. (Dorji, 2006). The employee perception of OHS uses in the workplaces withstands strongly here in the studies, as the mindset of the employee is

seriously important in the construction field. The employee is a key player in the construction industry. The value and concept of OHS need to be groom as well as it should be adhered appropriately. To commence the OHS in the respective construction site (Zanko, 2012).

However, the OHS implementation at the construction site is the question mark for the Employee. The lack of the idea and knowledge on the OHS execution gives the employee a cluelessness to claim for the benefit of safety gears. The keeping same track adopted on OHS will have a great life in the construction period as the employee can have the lifesaving on hands. The most importantly the purpose of preserving the OHS in the construction firm has to be embedded with the contractor, employee, and engineer (Israel, Baker, Goldenhar, Heaney, & Schurman, 1996).

The significance of OHS signaling great efficiency in the construction firm. The signing of the Memorandum of Understanding in the theme of health and safety was also stimulated in between the Construction of Board and MoLHR (2020). Similarly, the Ministry of Work and Human Settlement had executed OHS in the Bhutan Standard Rate 2021, and the ministry even had issued an executive order to the implementation of OHS in the tender documents. To have a potential platform for the construction firms.

To strengthen OHS in the construction firm, the engineers had enforced OHS in the bill of quantity to have a better environment for the contractor as well as for the employee at the construction site. Furthermore, for the safety of the employee, the PPE is implemented to minimize exposure to a hazard and to ensure safety measures at the construction sites at all the time. The perception of the OHS has to be determined by the engineer. To have the sustainability in the enforcement of the safety gears at the respective construction site and to motivate hereafter to the contractor, for the security of the employee's safety in the construction site (A.M. Makin*, 2008). The PPE is set into two phases, the first phase set of PPE includes a safety helmet, Safety Shoes, Protective Gloves, High Visibility Vest, and a Dust mask. The second phase set of PPE provides to the specific worker safety belts, Safety Harness, Safety Goggles and Spectacles, Ear Muffs, Ear Plugs, and welding shields or glass.

In addition, the Common Protection Measures (CPM) is to facilitate medical first Aids instantly at the construction site for the minor casualty in the first step, The recoding of the medical history of Employees, executing adequate safety signs and signboard at the site, keeping awake from the Fir and electrical safety, The fall protection, Boundary fencing of the construction site, and finally regulating the housekeeping practices at the respective site to have a clean and hygienic atmosphere in the workplace.

Similarly, Life Insurance is the best gift to the families and self, as it helps in the positive round as well as in the negative round in the background. The positive drive here is the insurance companies bless their share claimed or compensation claimed in the favor of the victim. The negative outflow tears the bereaved family, employers, and co-workers (Viscusi, 1973.1983). A Life and death can't be a gamble here, the preserving and promoting OHS can transform the greater lifestyle of the employee.

Research Questions

The central question is framed here to study the conceptual analysis of OHS in the construction industry under Tsirang Dzongkhag.

1) How effectively the OHS were implemented in the construction industry?
2) To determine the perception of contractors, employees, and engineers towards the essence of OHS in the construction industry.
3) To examine the availabilities of the safety equipment of OHS in the construction industry.

Data and Method

The quantitative method is used in this study to analyze the data of OHS obtained from the construction firm. The structured survey questionnaire was designed to acquire relevant information from the target participants; Contractor, employee, and Engineer through online access as well as face- to-face. The questionnaires were bifurcated into three themes such as perception of the implementation of OHS by contractors, perceptions of the use of OHS by the employee, and perceptions on the implementation of OHS by the Engineers. In addition, the observational note was maintained to supplement the data gathered from questionnaires and the findings.

Population and Sample

In this study, the population focused are contractors, employees, and engineers under the Tsirang district. The participant involved in the survey questionnaire is contractors, employees, and engineers under Tsirangtoed, Mendrelgang, and Damphu area which was selected based on the convenience sampling method.

Data analysis

The quantitative data were analyzed using SPSS version 22. The demographic information of the participants was also coded and reverse coding was also carried out with all the negative statements. Similarly, the observational notes were quantified and transcribed with

the theme of the study.

The perception of contractors, employees, and engineers

The data analysis on perception towards OHS was done with mean and standard deviation. The means and standard deviations were used to determine the level of perceptions base on the scale range adopted from the (Sherpa,2013). The scale range is shown in Table 1 below. Level of perception : 1-1.50 strongly disagree, 1.51-2.50 Disagree, 2.51-3.50 Neutral, 3.51-4.50 Agree, 4.51-5.00 strongly agree.

Table 1: Scale range to determine the level of perception

Means Score	Perception
1-1.5	Strongly Disagree
1.51-2.50	Disagree
2.51- 3.50	Neutral
3.51-4.50	Agree
4.51-5.00	Strongly Agree

Results and Findings

Survey Questionnaire

The survey respondent comprising of 14 Contractors, 71 Laborers, and 19 Engineers (n=104) were completed in this study. The Table 1 represents the status of targeted respondents such as contractors, Employees, and Engineers under the Tsirang district.

Table 2: Numbers of Respondents

Respondents	Frequency	Percentage (%)
Contractors	14	13.46
Employees	71	68.27
Engineers	19	18.27
Total	104	100.00

Table 3: Descriptive Statistics of Contractors' items in Likert Scale

SN		N	Minimum	Maximum	Mean	Std. Deviation
1	I assure you that all the Labors use thesafety Kits.	14	2	5	3.3571	1.15073
2	I facilitate all the safety kits all the time on the construction site.	14	2	5	3.6429	0.8419

3	I often advise about the Safety precautionof labor in the construction site.	14	2	5	3.8571	1.02711
4	Physical Protection Equipment measures such as Helmet, Goggle, Hand glove, safety Boot, Safety harness are lifesaving at my construction site.	14	2	5	3.6429	0.92878
5	I have failed to procure safety kits at thesite.	14	1	5	3.1429	1.29241
6	I have an idea about Occupational HealthSafety.	14	2	5	3.8571	1.02711
7	My employees are aware of the labor and Employment act of Bhutan 2007.	14	1	5	3.1429	1.46009
8	I have reserved the Life insurance schemefor the labor.	14	1	5	2.9286	1.07161
9	I have age limits irrespective of gender on the construction site.	14	1	5	3.8571	1.23146
10	My Employees are concern about havingsafety measures at the construction site.	14	2	5	3.5714	1.01635
	Total				**3.5**	**1.1**

The average mean of (M=3.5) and standard deviation (SD=1.1) of the contractors perception towards OHS. This indicates that contractors were in "Neutral" (2.51-3.5). The finding states that contractors are in the elasticity mode in implementing the OHS in the construction industry.

Table 4: Descriptive Statistics of Employees' items in Likert Scale

SN		N	Minimum	Maximum	Mean	Std. Deviation
1	I'm glad to use the safety Kits all the time at the construction site.	71	1	5	4.0986	0.81337
2	The facilities of safety kits are abundantly available on the construction site.	71	1	5	3.3803	0.9909
3	I often advise about the Safety precaution of labor in the construction site.	71	1	5	3.9296	0.79864
4	Physical Protection Equipment such as Helmet, Goggle, Hand glove, safety Boot, Safety Harness is lifesaving at my construction site.	71	1	5	4.2535	0.8232
5	I have failed to use safety kits at the site.	71	1	5	3.4085	0.99395
6	I have an idea about Occupational Health Safety.	71	1	5	3.4648	1.10623
7	I'm aware of the labor and Employment act of Bhutan 2007.	71	1	5	2.7606	1.13973
8	I believe that the Life insurance scheme is essential.	71	1	5	4.2254	1.00281
9	The age limitsare required on the construction site.	71	2	5	3.9577	0.83558
10	Safety measuresare important at the construction site	71	3	5	4.2958	0.57057
	Total				3.8	0.9

The average mean of (M=3.8) and standard deviation (SD=0.9) of the employees perception towards OHS. This indicates that employees were in "Agree" (3.51-4.50). The finding states that employees are much concerned about their health and safety in the construction industry.

Table 5: Descriptive Statistics of Engineers' items in Likert Scale

SN		N	Minimum	Maximum	Mean	Std. Deviation
1	I assure you that all the Labors use the safetyKits.	19	1	5	3.4737	1.30675
2	I facilitate all the safety kits all the time onthe construction site.	19	1	5	3.7895	1.22832
3	I often advise about the Safety precaution oflabor in the construction site.	19	3	5	4.4211	0.60698
4	Physical Protective Equipment such as Helmet, Goggle, Hand glove, safety Boot,Safety Harness are lifesaving at my construction site.	19	1	5	4.4737	1.02026
5	I have failed to enforce safety kits at the site.	19	1	4	2.3158	1.10818
6	I have implemented Occupational HealthSafety in the Bill of Quantity.	19	1	5	4.0526	1.12909
7	Contractors and employees are aware of thelabor and Employment act of Bhutan 2007.	19	1	5	3	1.24722
8	I support the Life insurance scheme for thelabor.	19	3	5	4.3158	0.67104
9	The age limits irrespective of gender aremandatory on the construction site.	19	1	5	3.8421	1.01451
10	Contractors and employees are concernabout having safety measures at the construction site.	19	1	5	3.1053	1.41007
	Total				3.7	1.1

The average mean of (M=3.7) and standard deviation (SD=1.1) of the engineers perception towards OHS. This indicates that engineers were in "Agree" (3.51-4.50). The finding states that engineers emphasize more on the OHS amendment to have the greater benefit to the employees in the construction industry.

Conclusion

This study was mainly intended to investigate the conceptual analysis of the OHS in the Tsirang Dzongkhag. The finding from the studies indicates that the engineers and employees had truly "Agree" with the vitality of OHS. However, the contractors were the least concerned about the employees health and safety in the construction industry. Similarly, the ILO and

WHO had clearly stated the essence of the OHS in the construction industry. Moreover, In the final count of the employees even supports the ILO and WHO mandates.

Despite the enforcement of the Labor and employment act of Bhutan, 2007, and regulation of welfare (WHO & MOHLR, 2012). The contractors are much reluctant about the health and safety of the employees. Therefore, to awake and encourage the contractors for the OHS, the concerned stakeholders and procuring agency need to focus more on the vitality of OHS, and strict compliance of OHS by the contractors will have the better health and safety of employees. The OHS was not effectively implemented in the construction industry of the region.

Limitations and Suggestions for the future

1) Owing to the inadequate resources, time, and expertise, this research was focused only on the Tsirang Dzongkhag, Bhutan.
2) The study was only focused on the Tsirang Dzongkhag, The findings will not be generalized, but to understand the conceptual analysis of the OHS within this Dzongkhag
3) For future development, the researchers can focus on the remaining Dzongkhags to get valid findings with additional tools. To incorporate in the construction firms, Corporation Organization, and to the government.

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