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

Tshering Penjor [1*], Tshering Dendup [2], Sangay Penjor [2*]

[1&2] Architecture Department, College of Science and Technology, Rinchending: Bhutan,*

[2] Civil Engineering Department, College of Science and Technology, Rinchending: Bhutan,

[1]email: tshering.pens100@gmail.com/ tsheringpenjor.cst@rub.edu.bt*

Abstract: Bhutan is a mountainous country with dense vegetation cover and its communities are mostly agrarian society, with most of them drawing their primary raw materials from the forest and agriculture. The native architecture style often seemingly Tibetan, have 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 revitalizes the existing conventional precautions and incorporates suitable interventions like material discontinuity in construction water mist sprinkler system from relatable cases for a better cause.

Keywords: Fire Safety, Timber, Material Discontinuity, Water Mist Sprinkler System, Rabsel Window

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

This research attempts to identify and determine suitable methods of fire prevention and control system in traditional Bhutanese buildings. 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.

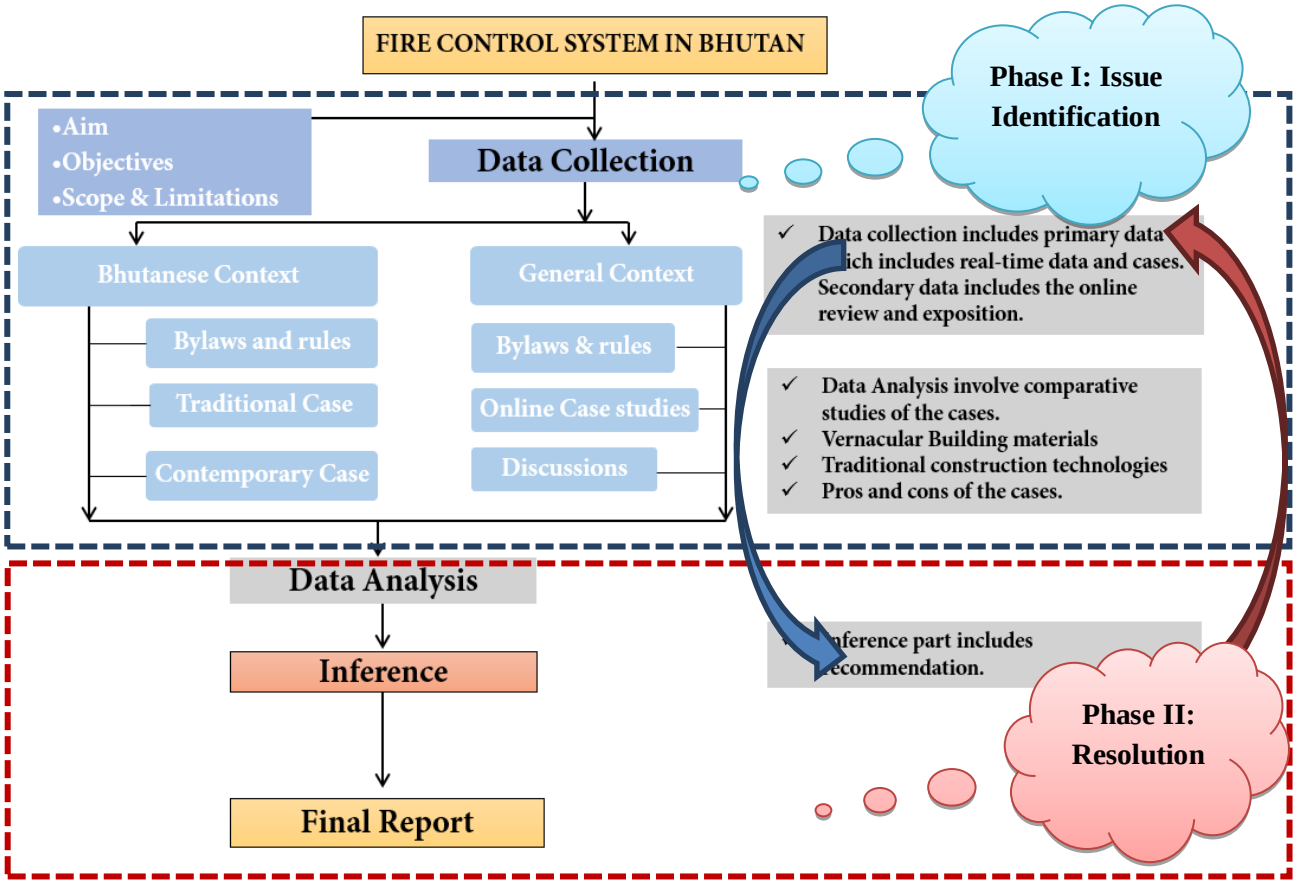


Figure 1. Methodology chart represented as the cyclic realization between twofold phases. Source – Authors

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 Department of Disaster Management (DDM, Bhutan) 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 below (Volumetric quantification in SketchUp).

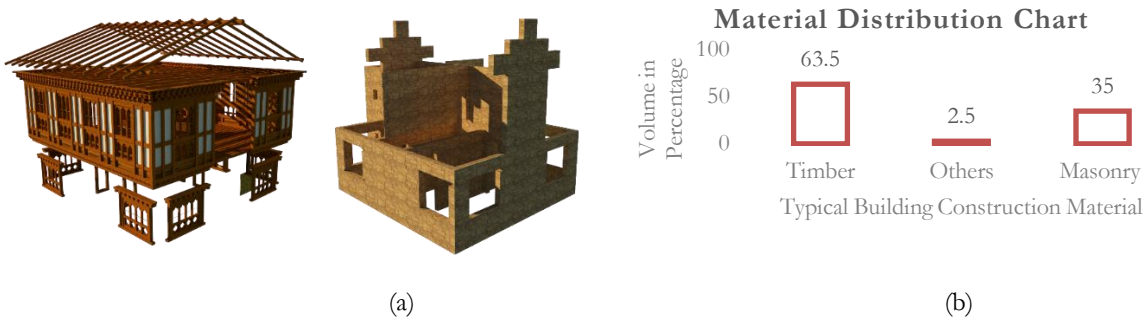


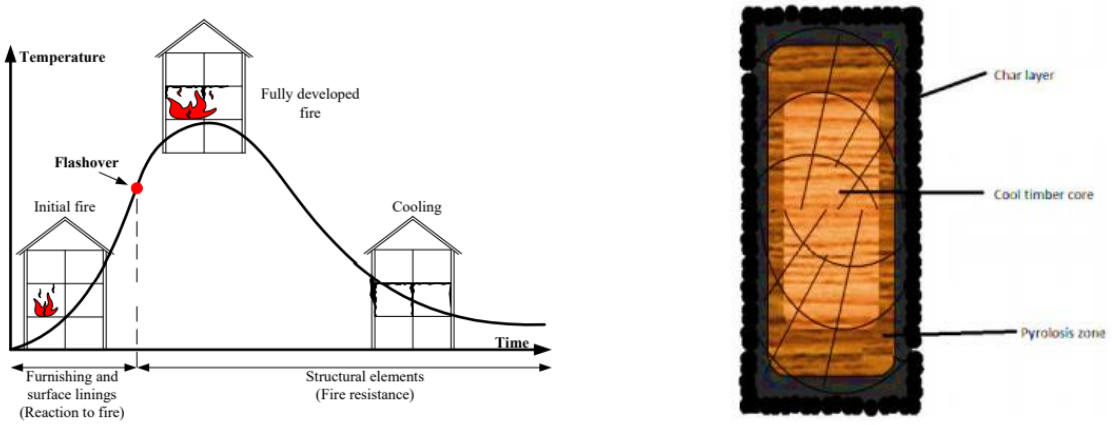
Figure 2. (a)Building Components of the traditional building in Ura. (b)Building material distribution chart. Data source – Authors

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.



(a) (b)

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.

Table 1. Comparative studies among the cases

Parameters	***Traditional House in Ura***	***Wangdi Phodrang***	***Mental Health***	***Hedareds Stave***	***Residential Building in***

		Dzong	***Facility***	***Church***	***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

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.

Material Discontinuity and Water Sprinkler System

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.

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 Dawa

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 go 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 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.

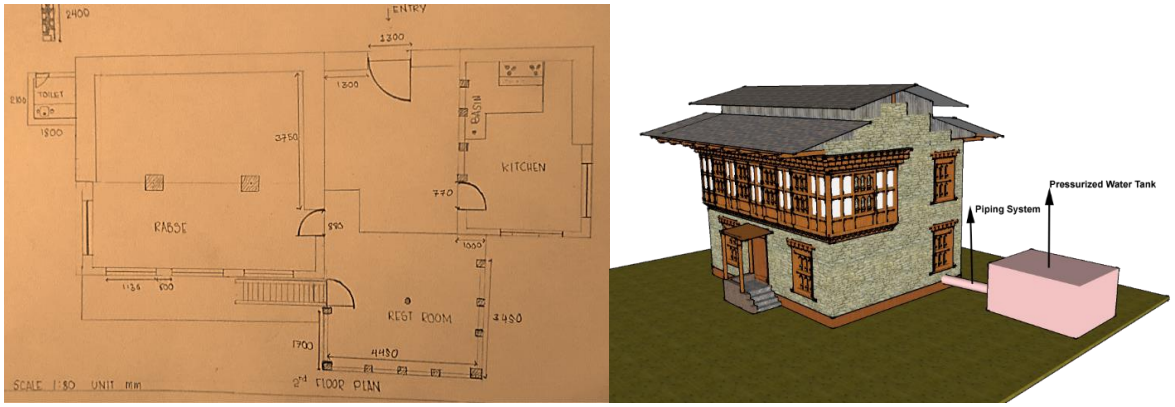
Overhang technique

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.

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.



(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

Water-mist Sprinkler system as a suitable fire suppression technology

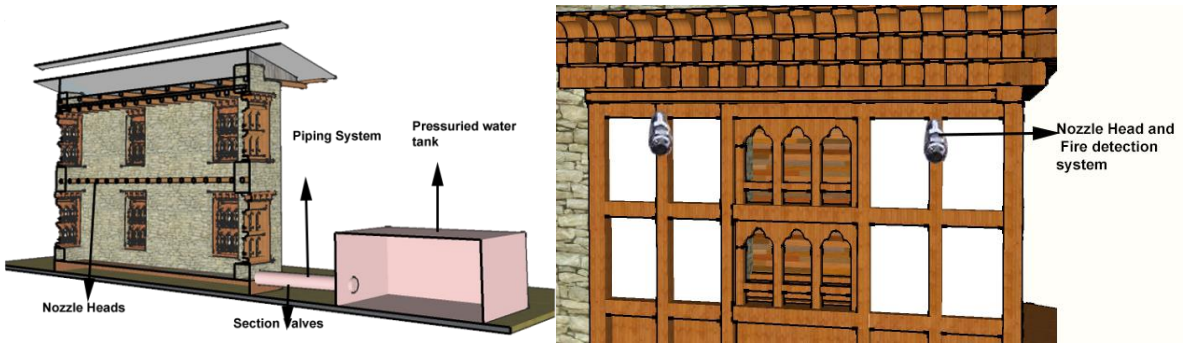
Occurrence of large timber fenestration and wooden shingles roof on the structure has been always threat to the fire outbreak in Bhutanese houses. During the last few decades, approximately one important and significant structure is raised to the ground by the fire. In the last few years Chamkhar town 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 caught by fire.

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

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.

Awareness & 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 evolved 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 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.

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, stated the Department of Disaster Management report, 2018. With the recent loss of Wangdi 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.

A wide range of case studies including both conventional as well as external references have been made to draw a generalized finding at last. Contextual cases like a house from the central Bhutan, Ura and Wangdi Phodrang dzong have been explored to clearly dig out the root cause and validate its true construction conformability with the evidences reported. Online cases include wider perspectives: from Sweden to Malaysia in which the intend of the research and the sameness of the place geography had been the key consideration.

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 its 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 intervention could be 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.

Acknowledgement

Our heartfelt gratitude goes out to all the people who are directly and indirectly involved in making this research a successful journey. Firstly, we are sincerely grateful to Miss Sehba Saleem (Assistant Professor) for her invaluable feedbacks throughout the research. We would like to mention College of Science & Technology and Ministry of Works and Human Settlement have been one of our primary sources and we will not forget their invaluable support in providing resources. Finally, it comes to Ap Sangay Tenzin of Ura for letting us carry on thorough case study at his house.

Had it not for all the names mentioned above; this research would be incomplete. So, we would like to thank you all once again for your invaluable support.

References

(2A), A. S. (2016). *Ura Documentary.* Phuentsholing: College of Science & Technology.

Aksamija, A. (2015). *High performance building envelopes: design methods for energy efficient facades.* Moscow.

Avidson, M. (2016). *Fire Suppression Installations for Wood Churches in Sweden.* Stockholm: Boras.

Dargye, Y. (2016). *A Brief Overview of Fire Disater Management in Bhutan.* Thimphu: National Library.

DDM. (2017). *Bhutan Disaster Risk Management Status Review.* Thimphu: MoHCA.

DHS. (2018). *National Building Code of Bhutan.* Thimphu: MoWHS.

Dujardin, M. (2006). *From Living to Propelling Monument.* Germany: Department of Architecture.

Dujardin, M. (2006). *From Living to Propelling Monument: the MonasteryFortress (dzong) as Vehicle of Cultural Transfer in Contemporary Bhutan.* Thimphu: Journal of Bhutan Studies.

England, P. (2016). *Australian building code change – 8 storey timber.* Veinna: World Conference on Timber Technology.

Gireendra Kumar & Gaurav Raheja. (2016). Design Determinants of Building Envelope for Sustainable Built Environment: A Review . *INTERNATIONAL JOURNAL OF BUILT ENVIRONMENT AND SUSTAINABILITY*, 4-10.

How Seng Guan, J. T. (n.d.). *Case Study of building services in Public Buildings.* School of Architecture, Building and Design.

ICC. (2018). *International Fire Code.* Newyork: ICC.

Jatinder Kaur. (2017). Thermal Performance of a Building Envelope: an Evaluative Approach. *IJRAR- International Journal of Research and Analytical Reviews*, 122-128.

Judith Schulz, J. C. (n.d.). Special Design of Smoke Detection System in a Mental Health Facility in New Zealand.

Kausik Sen, J. S. (May 2015). Automated Fire Detection and Controlling System. *2*(5).

Luis A. Alonso, B. L. (n.d.). A New Envelope with Highly Energy-Efficient Insulation.

Mukai, J. (2013). *Wangdue Phodrang Dzong Conservation Report.* Thimphu: Kuensel Cooperation Limited.

Östman, B. A.-L. (2013). *Fire safety in timber buildings.* Stockholm, Sweden: SP Wood Technology.

PHCB. (2017). *Population Housing and Census of Butan.* Thimphu: MoWHS.

S.Chungloo, B. a. (3rd july 2001). Parametric Analysis of Energy Efficient Building Envelope in Thailand.

Sedjo, R. A. (2012). Adaptation of Forests to Climate Change.

Wangdi, N. (2017). *Fire Destroys Six Buildings & 22 Shops.* Chamkhar: Kuensel.

Yaun, E. (2012). *Bhutan Grieves for Destroyed Historic Site.* Newyork: CNN.

Zorig Chusum. (2002). Arts and Crafts.

About Authors

Mr. Tshering Penjor and Mr. Sangay Penjor is Assistant Lecturer at under Architecture Department, College of Science and Technology (CST), Royal University of Bhutan. Both of them pursued Bachelor of architecture from CST. Mr. Tshering Dendup is Assistant Lecturer

under Department of Civil Engineering, College of Science and Technology. He pursued bachelors of Civil Engineering from CST.

From left to right - Mr. Tshering Penjor, Mr. Tshering Dendup & Mr. Sangay Penjor