AUTOMATED CHECKING OF CODE COMPLIANCE AND DEVELOPMENT OF EVACUATION PATHS FOR EMERGENCY EVACUATION IN BUILDINGS THROUGH BIM

FINAL YEAR PROJECT UG 2016

By

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This is to certify that the

Final Year Project Titled

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has been accepted towards the requirements
for the undergraduate degree in

Bachelor of Engineering in Civil Engineering

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ABSTRACT

Human life is regarded as the most precious thing on earth. During emergencies, most of the accidents occur while attempting to escape from the building. To ensure the timely efficient evacuation of people from the buildings, different building safety codes/regulations have been developed. The process of compliance checking is usually done manually that leads to inconsistencies in the application of compliance with prevailing regulations. Automation of code compliance through Building Information Modeling (BIM) removes the possibility of human errors from these processes and ensures codes are correctly adhered to. Therefore, there is a need for an automated compliance checking process. This study aims to formulate a process for automated development and checking of code compliance through BIM-based visual programming. Firstly, the identification and assessment of existing risks present in buildings for emergency evacuation are carried out. Secondly, by developing a parametric 3D BIM model and application of BIM-based visual programming, a process is developed for compliance checking and development of an emergency evacuation plan in buildings in compliance with international safety regulations. The study results in developing an automated checking and development of an emergency evacuation plan for buildings by using risk management processes in compliance with the prevailing safety regulations. The study aims to benefit all the humans present in public buildings during emergencies.

We dedicate this thesis to our family and teachers who have supported us in this challenging journey.

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LIST OF ABBREVIATIONS

2D	–	Two Dimensional
3D	–	Three Dimensional
4D	–	Four-Dimensional
5D	–	Five Dimensional
AEC	–	Architecture, Engineering, and Construction
AHJ	–	Authority Having Jurisdiction
API	–	Application Programming Interface
BCA	–	Building Code of Australia
BCP	–	Building Code of Pakistan
BIM	–	Building Information Modeling
CAD	–	Computer-Aided Design
FEM	–	Finite Element Model
GDP	–	Gross Domestic Product
HVAC	–	Heating, Ventilation, and Air Conditioning
IFC	–	Industry Foundation Classes
ISO	–	International Organization for Standardization
MEP	–	Mechanical, Electrical, and Plumbing
NCC	–	National Construction Code
NDMA	–	National Disaster Management Authority
NFPA	–	National Fire Protection Association
OSHA	–	Occupational Safety and Health Administration
PEC	–	Pakistan Engineering Council
PES	–	Punjab Emergency Service
PMBOK	–	Project Management Body of Knowledge
PTC	–	Parametric Technology Corporation
USFA	–	United States Fire Administration

Chapter 1

1. INTRODUCTION

1.1 Background

In today's world, organizations around the world face uncertain events which occur in a different environment and can have different characteristics and impacts. Such events can have grievous fallouts for the organizations (Aven 2011). Any of these unpredictable events having negative effects are called *risks*. Risk management is a process of identifying, accessing, evaluating, and controlling the risk (Hubbard and Douglas 2009). Risk management is fairly a new concept in the building sector of Pakistan; therefore, this subject has been rarely researched (Choudhry and Iqbal 2013).

The initial stage in the risk management process is the identification of the risk. Among different types of risk/threats, fire constitutes a major threat to life and property (Xin and Huang 2013). In the province of Punjab only, Punjab Emergency Service (a.k.a. Rescue 1122) had responded to 138,272 fire emergencies (PES 2019) and had saved losses estimated over Rupee 186 Billion since the establishment of the service in 2007. An estimated of 904 people got injured in fire emergencies all over Punjab Province during the year 2016 only, which includes 221 in Lahore, 130 in Rawalpindi and 125 in Faisalabad (Naseer 2017). All these statistics show us the significance of Fire Risk Management.

Although the risk is inevitable, the loss incurred due to it can be alleviated by efficient risk management. We often see that in case of a major accident there is an unnecessary loss of human life. Moreover, it also causes huge environmental loss as well as property losses, highlighting the need for a more efficient risk management process (Johan Lundin 2002).

Educational institutes are the most vital pillars of society. Although safety systems are usually installed in the educational center, a significant number of accidents are reported frequently. These accidents can throw the normal operation of educational institutes into disorder by causing serious injuries to people, damage to structure loss of priceless scientific equipment, and documents. The most important aspect when accessing the risk in the building is to examine how the building will be evacuated. As there are a large number of people present in educational buildings and the structure is typically complex, evacuating people can become a major problem which then leads to unnecessary loss of human life. So, evacuation becomes the most important parameter in the risk management process, and by the provision of efficient evacuation plans, it can be easily facilitated (Manouchehr Omidvari 2015).

Some of the notable factors that contribute to fatalities are “egress problems” and “escape problems”. These two factors combined contribute to 37% of total fire fatalities. Egress problems include factors such as crowded situations, limited exits, locked exits, or other exit problems, as well as mechanical obstacles to the exit. Escape factors include unfamiliarity with exits, excessive travel distance to the nearest clear exit, choice of an inappropriate exit route, re-entering the building, and clothing catching on fire while escaping (USFA 2017). By providing timely efficient evacuation plans to the user in need, these fatalities can be significantly reduced.

In order to guarantee the safety of people, the construction industry has focused on risk/disaster prevention management of buildings. This includes designing escape routes, escape route simulations, educational training, etc. (Eastman 2011). In the present-day world, the construction industry has actively using the Building Information Modeling (BIM) technology to develop three-dimensional (3D) models. BIM technology has been used under all its possible applications, which also includes the element of risk management (SERTYESILISIK 2017). BIM technology allows us to create 3D models and helps in Risk Management.

The effective planning of the emergency evacuation system is the way forward to ensure the expeditious, organized, and effective evacuation of people in the occasion of a major accident. The elements of risk identification and assessment should also be incorporated into the initial design and plan phase of new building/construction projects. It is essential that architects and engineers must assess whether the building, the escape routes and fire safety equipment meet the prevailing regulations (Frantzich 1994). Once the building is complete and is now in operation phase, the users/occupants of the building must be aware of the escape routes in case of an emergency. The maintenance staff should also ensure that these emergency exits are regularly kept maintained.

1.2 Problem Statement

The idea of implementation of intelligent information systems such as BIM has been significant in the construction industry (Gibson 1999). Developing nations such as Pakistan still lag in the true utilization of BIM technology. In Pakistan, the current state of adopting BIM technology is not satisfactory. A research study by R. Masood et al. shows that only 27% of Architecture, Engineering, and Construction (AEC) organizations in Pakistan use BIM technology in any capacity or are in the process of adopting it. The study further states that the barriers in the adopting process of BIM are being shattered which is the result of increased awareness about the advantages and applications of BIM (Rehan Masood 2014).

The construction industry at the present does not have an efficient emergency evacuation development tool to account for the safe exit of people in case of any natural calamity. It is, therefore, a need of time to establish an efficient evacuation plan of a building encompassing all the aspects of hazard and public response to the emergency.

Moreover, the Fire Safety Provisions were recently added in 2016 in the Building Code of Pakistan (BCP). This shows that there is a lack of planning and implementation in the field of fire risk management in Pakistan. Therefore, there is a need of developing an automated emergency evacuation plans for buildings by using risk management processes which are also in compliance with the prevailing safety regulations.

1.3 Objectives

- To identify and assess the existing risks present in existing buildings for emergency evacuation.
- To formulate processes for
    a. Automated checking of code compliance for emergency evacuations in buildings.
    b. Development of automated emergency evacuation paths in buildings through BIM-based Visual Programming.
- To validate the processes on the developed BIM model.

1.4 Areas of Application

This research can be applied to all kinds of buildings, however, in this project, the main focus was on educational institutes. These automated evacuation plans comply with prevailing operational safety regulations of buildings. By providing timely efficient evacuation plans to the user in need, fatalities can be significantly reduced.

Chapter 2

2. LITERATURE REVIEW

2.1 Background

In order to save precious human life in case of emergencies like fires or earthquakes, the generation of efficient emergency evacuation plans is of high importance (Karimi 2016). Statistics show that many fatalities in case of emergencies occur primarily due to a lack of reliable or poorly managed evacuation facilities. Therefore, risk assessment for emergency evacuation in buildings in case of extreme events can be greatly useful for prevention, mitigation, preparedness, and response (Shi-qi Tong 2017) (James P. Bagrow 2011).

The process of risk assessment of public buildings is highly complicated. Usually, the risk assessment is done based on some design criteria which can vary from country to country. These design criteria only take into account the structural complexity of the building and the number of emergency exits that are provided. However, this does not take into account the uncertainties that the evacuee can face during evacuation. Moreover, the total number of evacuees and their initial position also affects the evacuation process. Due to a large number of uncertainties, risk assessment becomes highly complicated (Ning Ding 2017).

2.1.1 Losses Incurred Due to Fire Accidents in Buildings

Any intentional or accidental fire in the building that may endanger human life or cause damage to the structure can be characterized as a fire risk. As the world around as is developing and transforming rapidly, so are the risks associated with it becoming a growing concern. According to the statistics, in the past two decades, more than one million people lost their precious lives in fire accidents around the world (Nikolai Brushlinsky, World fire statistics 2017). Moreover, these fire accidents caused an annual loss of nearly $1 Trillion (US dollars) annually, which is around 1% of the global Gross Domestic Product (GDP) (Bulletin 2014). In developing countries around the world, these fires took the life of 44,300 people (Nikolai Brushlinsky, World fire statistics 2017). The developing countries like Pakistan and India have the highest number of deaths related to fire accidents in the world, ranging from 10 thousand to 25 thousand annually (Nikolai Brushlinsky 2016). These statistics show how important it is to provide proper fire safety and efficient emergency evacuation plans in the buildings.

2.1.2 Fire Accidents in Pakistan

- **PUNJAB PROVINCE**

In the province of Punjab only, Punjab Emergency Service (a.k.a. Rescue 1122) had responded to 138,272 fire emergencies (PES 2019) and had saved losses estimated over Rupee 186 Billion since the establishment of the service in 2007. An estimated of 904 people got injured in fire emergencies all over Punjab Province during the year 2016 only, which includes 221 in Lahore, 130 in Rawalpindi and 125 in Faisalabad (Naseer 2017). Detailed statistics are shown below:

Table 1 – Fire Emergencies in Punjab Province from 10-Oct-2004 to 07-Dec-2019 (PES 2019)

District	Fire Emergencies	District	Fire Emergencies
Lahore	34725	Rawalpindi	9123
Faisalabad	14835	Multan	8406
Gujranawala	8925	Bahawalpur	3626
Sargodha	3645	D.G. Khan	3482
Sahiwal	3355	Sialkot	5940
Rahim Yar Khan	3069	Murree	715
Jhang	2226	Khanewal	2158
Rajanpur	1298	Muzaffargarh	1165
Gujrat	2099	Bahawalnagar	1639
Attock	1305	Jehlum	1122
Toba Tek Singh	998	Pakpattan	922
Mianwali	1329	Kasur	1896
Vehari	1675	Chakwal	940
Okara	1843	Hafizabad	2196
Sheikhupura	2866	Lodhran	1356
Nankana Sahib	1973	Khushab	845
M.B. Din	1530	Narowal	1755
Layyah	955	Bhakkar	1027
Chiniot	1308	**Total**	**138272**

- **KARACHI CITY**

Following are the details of several fire accidents in Karachi:

The Garment Factory "Ali Enterprises"

On 11th September 2012, a garment factory in the city of Karachi caught fire. Around four hundred (400) people were working inside the factory. 258 people died in the result of this fire. Moreover, the loss in terms of capital was somewhere between $10 million to $50 million. The factory was a source of income for around 1200 – 1500 workers (Zia Ur Rehman 2012)**.**

Karachi's Regent Plaza Hotel

On 5th December 2016, a 10-story hotel in Karachi caught fire due to electrical problems. There were no fire alarms or emergency exits provided in the building, which resulted in the death of 12 people and 75 people were severely injured while trying to escape (Junaid Feroze 2016)**.**

Rajwani Denim, Karachi

On 10th March 2017, a three-story industrial building in Karachi caught fire. The fire kept burning for almost three days due to the poor response from the city administration. Luckily it was Friday and all the workers were gone to pray Jumma prayer, otherwise, it could have been deadlier than Baldia factory fire (Dawn 2017)**.**

Foam Factory, Zia Moor, Karachi

On 5th July 2018, the fire erupted in a foam factory located in Karachi's SITE area. 5 firefighters got severely injured in the process of controlling the fire but were unable to control it. Luckily, it was early morning when the incident occurred, and no one lost their life. But the incident resulted in damage of around $1 million (Point 2018)**.**

2.2 Fire Safety Bye-Laws/Provisions

A large number of causalities and injuries occur every year due to the fire incidents. Around 70% of causalities occur in commercial, industrial, and residential buildings due to lack of provisions for safety and fireplace protection systems (BCP 2016). The most common cause of fire hazards and emergencies of non-compliance, at 13.7%, due to inadequate fire risk assessments, and the second major factor was improper fire exit and escape routes i.e. 11.8% (Health and Safety Authority 2013-2014).

Every country has building codes and bye-laws that supply the guidelines and smallest necessary requirements to ensure safety and sustainability in the design and construction of new buildings. These codes, standards, and bye-laws have developed over time and are also updated and amended according to the modern needs of society. Every building code has a specific section or part which is specifically dedicated to fire safety, and here we will be discussing a few of them.

2.2.1 Bye-Laws in the United Kingdom

In the United Kingdom (UK), building regulations are statutory bye-laws to ensure that the buildings are safe for the inhabitants and their users. These regulations are set out in the Building Act of 1984. The regulations under this Act are parodically revised and updated. The most recent version of the bye-laws is the Building Regulations 2010. These bye-laws have 16 separate headings which are designated by a letter starting from Part-A and ending at Part-Q. These parts cover aspects such as workmanship, adequate materials, structure, waterproofing and weatherization, fire safety and means of escape, sound isolation, ventilation, safe (potable) water, protection from falling, drainage, sanitary facilities, accessibility and facilities for the disabled, electrical safety, security of a building, and high-speed broadband infrastructure.

The Part-B of the Building Regulations is related to fire safety in a building. It covers all the aspects of fire safety given under five (5) different headings from Requirement B1 to Requirement B5 and includes early warning systems, evacuation sign, and plans, emergency exits, control of the internal and external spread of fire and accessibility for the fire rescue teams (The Building Regulations 2010, Part-B: Fire Safety).

Once the building is occupied and used, the “Responsible Person” is required to carry out a detailed fire assessment of the building to see how the inhabitants and users use the building. Further, it requires providing and maintain "suitable and sufficient" fire safety precautions at all times (The Regulatory Reform (Fire Safety) Order 2005).

2.2.2 Bye-Laws in Australia

The Building Code of Australia (BCA) which is contained within the National Construction Code (NCC) lays down the requirements to ensure the safety and sustainability of the building for its inhabitants and users. The NCC comprises of two separate volumes for commercial and residential buildings. The Volume 1 is for the commercial buildings whiles Volume 2 is for residential buildings. These bye-laws have 10 separate headings which are designated by a letter starting from Section A and ending at Section J. These sections cover provisions including but not limited to general provisions, structural, fire resistance, emergency evacuation, services and equipment, health and amenity, energy efficiency, special-use building, and ancillary provisions.

The Section C and D of the NCC Volume 1 is related to fire safety and emergency evacuation. These provisions provide guidelines for constructions of emergency exits, provision of escape routes, access for disabled people, and other fire safety bye-laws (NCC 2015).

2.2.3 NFPA Provisions

National Fire Protection Association (NFPA) based in Massachusetts was established back in 1896 and is an international non-profit organization. The focus of this organization is to reduce and eliminate death, injury, property, and economic loss due to fire-related hazards. NFPA has published more than 300 codes and standards that cover almost every aspect of fire-related risk. These codes and standards are administered by more than 250 Technical Committees and are adopted and used throughout the world (NFPA 2020).

NFPA 101 Life Safety Code is a consensus standard widely adopted in the United States. This provides standards for fire safety and emergency evacuations and covers aspects including but not limited to fire escapes, stairways, evacuations plans, evacuation drills, construction and arrangement of exit facilities, etc. The Authority Having Jurisdiction (AHJ) can enforce the standards as is or can make amendments according to the needs.

2.2.4 Bye-Laws in Pakistan

Pakistan Engineering Council (PEC) initiated the creation of the Pakistan Building Code (Fire Safety Provisions – 2016), which is benchmarked with National Fire Protection Association (NFPA 101) Life Safety Code (2015), in collaboration and financial assistance provided by National Disaster Management Authority (NDMA). These provisions provide a unified system of standards for fire prevention, fire protection, and life safety to protect human lives and reduce material losses to residential, commercial, and industrial buildings. Such provisions aid in hazard risk mitigation and disaster risk management in the event of fire accidents to reduce vulnerabilities and adverse impacts. These standards are applied to all public and private residential, commercial, and industrial buildings. These bye-laws will be revised every five years but can also be revised earlier depending on the feedback of the stakeholders. These provisions are kept updated by a PEC task force comprising of representatives from regulators, companies, industry, engineering professionals, and other stakeholders. Any change is suggested after open consultation (BCP 2016).

2.3 Risk Management

2.3.1 What Is Risk?

The word "risk" was used from the 17th century in the English language and originated from an original meaning of running in danger or moving against a rock (McElwee 2007). The definition of risk is currently being applied in several different ways and with different words such as "challenge", "threat", "danger" or "uncertainty". Risks in the AEC industry are of a double-edged type, e.g. "The probability of unwanted hazards and the subsequent effects" (Patrick X.W. Zou 2007), the possibility and effect of threats" (Williams 1996), "a mixture of the likelihood and consequences of the threat" (A. Vrouwenvelder 2001).

2.3.2 Risk Management

Risk management is a process designed to identify, measure, and control all of the threats that the organization or project presents. It is defined by Project Management Body of Knowledge (PMBOK) ® as a process relating to risk planning, identification, analysis, response, and monitoring (PMI 2004). The International Organization for Standardization (ISO) describes the risk management process requiring the implementation of a formal and logical approach for setting the context, providing a framework for communication and consultation to identify, assess, evaluate, handle, track, and document risk (ISO Standard 2016). Risk management in the sense of AEC is a rational, systematic, and rigorous method in compliance with these concepts to define and assess risks and handle them through communication and consultation to reduce the risk successfully. The systematic method involves detecting, analyzing, assessing, handling, tracking, and review of risks (Nerija Banaitiene 2012), where risk identification seeks to discover the spectrum of possible risks and risk analysis plays a central role in the entire process.

2.4 Building Information Modeling

"BIM is the process of using intelligent graphic and data modeling software to create optimized and integrated design solutions." (Holness 2008)

In simpler words, BIM involves the process of creating information models based on non-graphical as well as graphical information in a shared digital space. The information increases in complexity and richness over time as the project moves forward.

The use of BIM has gained more acceptance over the years owing to its wide range of functionality. The main product BIM provides is a 3D graphical model where each line and each product carries intelligent physical and performance data. It can also extend to 4D (adding the fourth dimension of time, through scheduling software) modeling and 5D (adding the fifth dimension of cost, through cost estimating software) modeling.

BIM is one of the most important developments in the field of AEC. Digital models of any building can be made with very high accuracy. These digital models become very helpful in the design phase and better analysis can be done as compared to the manual process. Once a complete and precise 3D model is generated, it will store in it the precise geometry and all the data that is needed throughout the construction process. The added benefits are the features that assist in the operation and maintenance throughout the lifespan of the building, which can further contribute to the better design of the buildings. BIM provides an environment of integrated design and construction, which when used to its full potential can help in lowering the cost and duration of the project. As there are various advantages of using BIM, including but not limited to saving time and resources while design and planning construction projects. That is why the AEC industry is showing an increased interest in BIM technology (Eastman 2011).

3D modeling started a long time back in the 1970s and was based on computer-aided design (CAD) technology. While many industries have made integrated analytics tools and object-based parametric models (being the basic concept of BIM), the construction sector has been restricted to traditional two-dimensional (2D) design for quite a long time. It was only until the early 2000s when BIM modeling started in a few pilot projects and assisted architects and engineers in the design phase of the construction project. Since then major research and development have been done in this field but it is centered around enhancing planning and design, conflict analysis, visualization, quantification, cost control, and data processing (Eastman 2011).

BIM simulates the building process in a futuristic, digital world. BIM creates a virtual/digital 3D image of the original structure, which is called the BIM model. After completion of the model, it helps in various construction phases such as design, procurement, and manufacturing. The Building Information Model has accurate geometry and all the related data necessary for measurement, visualization, and other processes for the construction process. It is important to note that BIM is not a specific software but rather a process.

Apart from developing smart 3D models, BIM technology helps in innovating and improving the conventional processes of workflow and project execution (Brad Hardin 2015). BIM technology creates a virtual platform and allows all the stakes holders (i.e. owners, architects, engineers, contractors, subcontractors, and suppliers) to work together which is by far more efficient and more effective than the conventional process (Jorge Carmona 2007). BIM represents a new paradigm within the AEC, promoting the integration of all stakeholder roles into a project. This also promotes an environment of mutual sharing of information and helps in uniting different stakeholders in one place, who in the past have been opponents of each other. This modern approach of integrated project delivery reduces delays and optimizes the efficiency of the whole construction process (Azhar 2011).

2.4.1 Applications of BIM

A BIM model can be utilized for several purposes as envisaged by the study (Azhar 2011).

• Visualization

3D renderings can be produced effectively and visualized easily.

• Shop Drawings and Fabrications

Shop drawings/models for different structure frameworks are very difficult to produce. For example, after the model is made, the metal sheet ventilation shop drawings can be delivered in no time.

• Code audits

It can be applied to audits of various structural components. Fire divisions and other regulatory building authorities may use these models for structural auditing.

• Cost assessing

BIM is useful when determining project costs. Material quantity is taken out and updated when any modifications are made to the cost calculation model.

• Sequencing of Construction

A BIM design model can be effectively used for all building components to organize material requesting, drawing up, and delivering plans.

• Conflict and Impact discovery

Since BIM data models are made to scale in 3D space, each real structure can be modified in a split second and thus tested for clashes.

It can check, for example, that Mechanical, Electrical, and Plumbing (MEP) pipes do not cross with steel bars, conduits, electrical components, and dividers.

• Forensic examination

A BIM data model can be adjusted effectively to allow for graphically clear possible disappointments, spills, clearing plans, etc.

• Faster and increasingly compelling procedures

Information about each aspect of the model is shared more effectively and can be updated and reused.

• Better structure

Building recommendations can be thoroughly dissected, re-enactments can be carried out efficiently and quickly, and execution can be benchmarked, enabling better and inventive arrangements. All the costs of life and controlled natural information.

Ecological execution is progressively unsurprising, as well as improved control of lifecycle costs.

• Better creation quality

The quality of design and documentation is better and integrated.

• Automated get together

In various procedures, digital item information can be reused and used to assemble auxiliary frameworks.

• Better client administration

Proposals are better checked and managed by exact perception.

• Lifecycle information

All the information about structural, electrical, MEP components, and other components is available with the model to be used throughout the usage and maintenance of the Building.

2.4.2 Technical Benefits

BIM offers a substantial specific development on customary CAD, which offers more control, more interoperability dimensions, and knowledge. Computerized interpretation of both practical and physical qualities of an office empowers clients to share design structure information among software applications, both within the association/department and in a multidisciplinary environment more generally. Since data is stored in a BIM database, any changes in the information needed during the planning stage can be consistently included and monitored during the project lifespan. BIM was defined as "the innovation in the production and management of a building's parametric model". It has additionally been mentioned as a developing multi-layered phenomenon with an object-oriented 3D model of a building to authorize data exchange and interoperability. It has also been referred to as a multi-faceted development phenomenon with a 3D object-oriented model of a building structure to allow data exchange and interoperability (Ali Ghaffarianhoseini 2017).

- **Data organization benefits**

BIM tools have empowered wide-ranging data related to the construction to be taken during the project, extending from specific construction components and spatial associations and connection between those items. BIM integrates construction data ranging from geometry, 3D links, light examination, topographical information, material quantities, and various properties of the material of the product building components, description, fire rating, furniture, textures, costs, and total carbon content. These structures enable designers, engineers, and contractors to track relations and linkages between building components and maintenance details of structural components. Although the designer/engineer recognizes BIM 's advantages, they may become obvious to other project participants such as owners, contractors, subcontractors, manufacturers, fit-outs, assembly companies, etc. Furthermore, BIM can also be used indispensable for competence administration incorporation. If there are any changes in design, BIM tools can participate, assemble, and keep track of all changes for the capability/project with the design principles and all design layers. BIM tools offer interoperability changes in addition to the capability for appropriate integration, permitting inputs from various authorities, and different BIM-based software to come together to exchange information in the model.

- **Calibration benefits**

Data exchange standards were developed to allow BIM users to fully exchange ideas, associations, information, and models. These standards were created in the form of Industry Foundation Classes (IFC) which develops standards for data exchange for structure items that were led by building SMART. This was a significant step forward in the process of creating the BIM. This was subsidized to allow and arrange interoperability between users of AEC, using different BIM platforms by establishing standard design models that include rich somesthetic information and geometric component data.

- **Assimilation benefits**

Recently, BIM has gained acceptance among key players in the architecture & construction industry to use it as an aid in the design and construction process. Similarly, to increase the AEC learning experience, BIM is expected to be operated for data integration. BIM has formed to encourage the expanding complex nature of development projects, organized to encourage plan, development, and maintenance of events through a synchronized procedure. It gives a community stage to all the partners associated with a task lifecycle in their respective fields. Owners, inventors, provisional workers, and development heads can use BIM to embrace development extends more effectively than at any time in recent memory. BIM can also be utilized as a smart manual book for securely supervision and working the structure giving total office data, for example, physical building structure, MEP, furniture as well as equipment. The BIM model can be utilized effectively for mated manufacture machines for pre-created steel or other constructing sections. Where a construction illustration relates to time, it is possible to rebuild the development procedure. BIM can be viewed as a key to the future of Design and Construction and upgrade of practicality housing and prudent constructions.

- **Financial benefits**

In addition, BIM has been recognized as having significant financial advantages. BIM customers have outlined the benefits of using BIM. BIM's most significant effect was to limit documentation errors. This has been tracked by using BIM as a business advertising device. Moreover, less staff turnover has been observed as the current advantage of using BIM. Less statutory binding cases and lower development costs are considered long-term benefits. Additionally, the continuing sporadic company with past clients is a remarkable benefit of BIM. For structure, the 3D BIM model will give a progressively rational observation of the plan. By improved joint efforts, a constant improvement between various plan controls can be accomplished, which essentially diminish building mistakes and errors. Any changes in the 3D model can be produced quickly to 2D illustrations. Financial assessments can be separated from the BIM model to keep all associated with it informed of the financial ramifications as the model is developed.

2.4.3 BIM Model Categories

There are different kinds of models, and a few definitions are given in the script and by the standards bodies:

- **Design Intent Model**

These models catch the expected plan and are utilized for task BIM execution, advanced structure mock-ups, special help, and coordination. The endorsed model is a contract description for submission to the administrator and development. The amount, size, shape, area, and outline of components are precise in this model; it contains one of a kind resource distinguishing proof numbers and integrates the Spatial Program model.

- **Building Model**

Established from the Design Intent Model, these classically characterize a single structure framework made for the reasons for positioning, planning, organizing, manufacturing parts, and executing development. Model components are precise and may integrate manufacture, assembly, itemizing, and non-geometric data.

- **Management Model**

This is a complex model that incorporates various design as well as constructed BIMs, enrolled spatially, and utilized for the reasons for interfering checking (conflict finding), awareness, and further BIM investigations within construction.

- **As-Built Model**

These models catch the conditions toward the completion of development and should be dependent on the design intent model and progressively consolidate scheme data as development advances characterize as-constructed models as editable duplicate of the Record BIM that is continually refreshed to characterize to the current finished condition of the construction and frameworks setup (Ali Motamedi 2018).

2.4.4 Current and Future Trends

- BIM clients spoke to all sections of the structure, development industry, and they worked all through the U.S.
- Developing archive improvement, computed plan, support, and pre-project management were key application areas of the BIM.
- The utilization of BIM brought down generally speaking danger dispersed with a comparative contract structure.
- At the term of the study, most organizations utilized BIM for 3D and 4D clash detection and conflict location.
- The utilization of BIM increased efficiency, the better commitment of undertaking staff, and decreased possibilities.
- A deficiency was noted of capable structure data modelers in the development business, and research was started to develop in this area (Shao-Jen Weng 2011).

2.5 Autodesk Revit

The only complete parametric Modeling software available today is Revit. It was originally created by U.S. based company Parametric Technology Corporation (PTC) which also created other popular software like the Finite Element Model (FEM) tool, Mathcad which are extensively used in the engineering field Originally it was only built for architectural purposes, i.e. for architects, it was built. Most people involved in its development are either architects or they come from a background in design and construction (Arkin 2007).

Autodesk Revit Architecture was fabricated utilizing parametric structure demonstrating innovation, in which structures are spoken to as an incorporated database containing both graphical and non-graphical information as In impact, past graphically portraying the plan, BIM models in Autodesk Revit Architecture contains parameters that can be utilized to speak to construction regulation learning and can be consequently caught amid the structure procedure for supporting code consistency checking (Shao-Jen Weng 2011). In Revit, each building or structure segment is linked to the ready-made parameters that are assembled into two classes: type parameters and occurrence parameters. The sort parameters regulate all components of the equivalent type while the case parameters control chose or made examples of the sort and occasion parameters are additionally ordered into various gatherings, so all parameter can be put away in various arrangements such as content, whole number, number, length, territory, volume, edge, URL, material, and some new parameters speaking to the information in construction standards can be made and put away as venture parameters which can be utilized to decide the code consistency of a structure part (Shao-Jen Weng 2011).

Now Revit is used as a BIM Software designed by Autodesk for engineers, architects, designers, and contractors. It allows users to develop a building and structure a 3D model, annotate it using the components of 2D drafting, and access the building information from the building model database. It can also be used to plan and track changes during different stages of construction such as planning, design, execution, maintenance, and subsequent demolition. It can be used for the design of a building by architectural, structural, and MEP.

- **Revit Architecture**

The design made on the Revit architecture is only for architectural purposes. It is not applicable for structural analysis and other analyses which are based on the structural design. The architectural components are doors, windows, architectural columns, openings, stairs, and floors. Energy analysis can also be done on architectural design.

- **Revit Structure**

Revit structure is used to design the structural model for the building. The main components of the structural model are beams/girders, columns, footings, and reinforcements, etc. Structural analysis can be done on the structural model.

- **Revit MEP**

MEP is a powerful tool of Autodesk Revit which is used in the designing of electrical/power, plumbing, drainage, and Heating, Ventilation, and Air Conditioning (HVAC) systems for the building.

2.6 Visual Programming

The designer intents always to thrive for more sophisticated building geometries. The ongoing development in CAD helps the designer overcome the restrictions and use the knowledge of computer programming to its best to make the most sophisticated building designs a reality e.g. using conditional statements and loops in parametric BIM. As the building designers have no substantial knowledge of traditional programming or code writing so visual programming languages and platforms had been introduced. Visual programming allows for a simplified and user-friendly way of replacing the traditional difficult code writing process with a visual metaphor of small blocks with different functionalities across a system or procedure. With visual programming, computer programs can be manipulated graphically rather than textually code writing. Several surveys show that non-programmers or beginner programmers better comprehend visual programming instead of traditional programming (Michael Bergin 2014).

Grasshopper and Dynamo are both based on the visual programming language (Python) and create numerous opportunities for designers using Rhino or Revit. In this study, Autodesk Revit and Dynamo have been used to have some differences form grasshopper. Some of the benefits of Dynamo are:

- **Customize Revit**

Dynamo lets users build automation routines for Revit without learning the Revit Application Programming Interface (API) which is difficult. This opens many opportunities for Revit users to customize their workflow without learning a lot.

- **Control model Information**

The building information modelers often say that the real power of the Revit is not just geometry creation but how the model information can be tracked and controlled, and Dynamo does this job very well. It lets the user design systematic relationships for manipulating parameters and model elements that would otherwise be impossible with Revit built-in tools.

- **Design with BIM**

There is often a misconception with BIM that it is only for production, not design. But with Dynamo this misconception is proved inaccurate. It allows the designers various iterative tools in the context of BIM.

2.7 Dynamo

Dynamo is the Autodesk Revit’s API that helps in creating additional tools, plug-ins, and add-ons to enhance the working of Revit and can be added to the Revit's integrated features. A few visual programming software that includes Maya Hypergraph, LEGO MINDSTORMS NXT, which is based on National Instruments LabVIEW, influences the user interface, and feel of the dynamo. As a parametric modeling program, it takes inspiration from McNeil’s Grass-hopper for Rhino and the Generative Components of Bentley. It is designed to take the parametric modeling capabilities of Revit to the next level by adding certain levels of the associativity of data and geometry that is not available in the Revit functionalities (Kensek 2014).

Dynamo was used for a number of applications, including the connection between the Arduino board, the light sensor, and the building information model. It was also used for various other applications due to its user-friendly interface for Revit. It helps in making and creating different view layouts and Revit sheets. Using its full potential, Dynamo can be used to fabricate architectural components, making fully automated virtual shading devices, measuring the values of the sun’s radiations, and changing Revit’s parametric geometry by manipulating a value slider in the Dynamo (Kensek 2014).

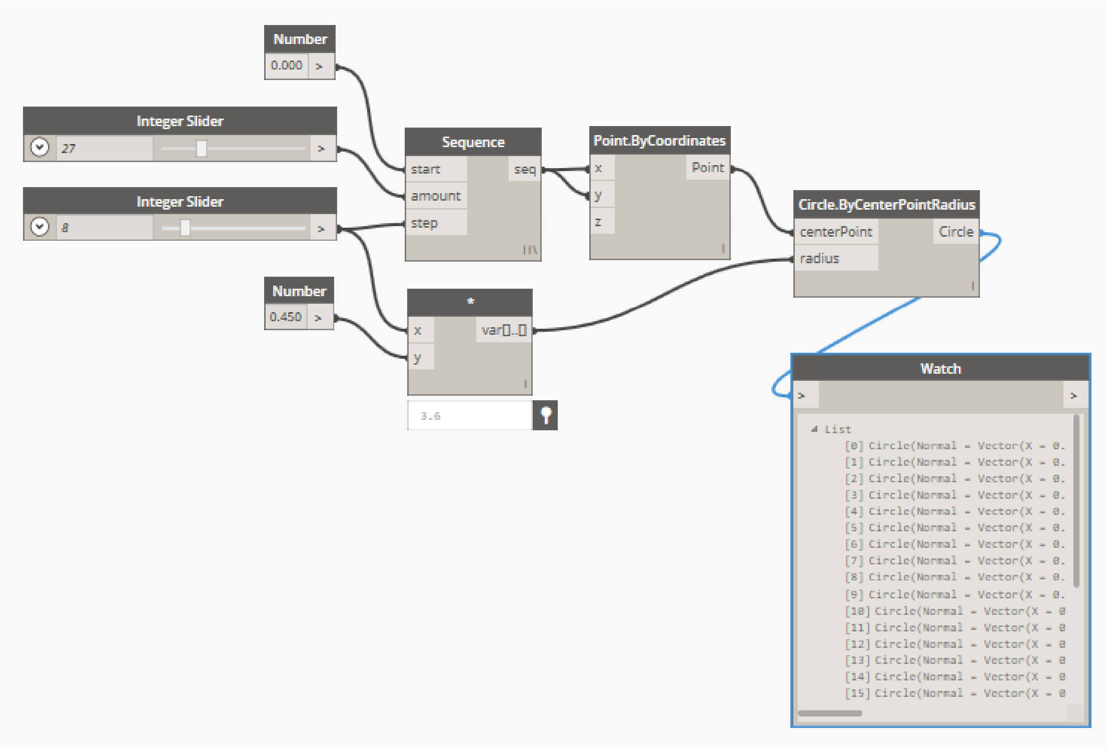

Figure 1 – Typical Process Flow in Dynamo

The Anatomy of Dynamo consists of mainly the nodes and wires. Dynamo is a visual programming language tool and the operations of data are executed by nodes and wires in the dynamo workspace. The nodes perform a function. The function or task which the node can execute can be very simple as adding two numbers or as complex as creating complex geometry. The language used for scripting the nodes is python. With some exceptions, the majority of nodes are composed of the following five parts:

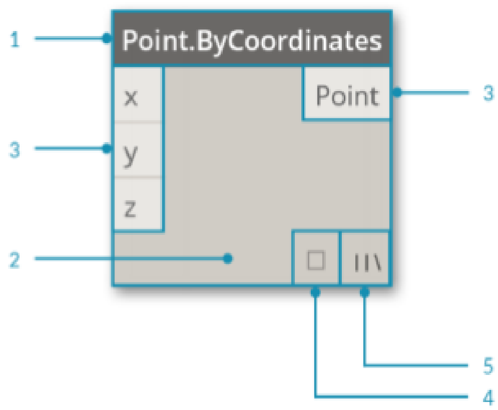

Figure 2 – Anatomy of a Node in Dynamo

1. Name of the Node.
2. Main Body: Right-clicking here presents options at the level of the whole node.
3. Input and output ports: Wires are connected through these ports.
4. Data preview: Results executed from the node can be viewed.
5. Lacing Icon: Indicates the lacing option specified for the matching list.

Connecting two nodes is simple as clicking on the output port of one node (a connecting wire will originate) and then clicking on the input port of the other node. Make sure to connect the right input with the node otherwise feeding the wrong input or data type will generate errors. The wires connecting the nodes transfer data like the electrical cables that transfer power.

2.8 Previous Research

There have been research efforts on integrating BIM with the evacuation problems in buildings. In the year 2012, using Revit's API, Wang et al. developed an add-in toolbox that helps in estimating the capacity and evacuation time of buildings (C.H. Wang 2012). This tool also checks the standards for public spaces. For the purpose of evacuation planning in the pre-design phase on any construction project, extensive BIM-based has been done so to avoid bottlenecks during the construction phase, and for checking the regulations for evacuation in tall complex structures (Jungsik Choi 2014).

In the year 2009, Chu et al. using cellular automata and Shi et al. by agent-based modeling made simulation models of building users to help in decision making during the time of emergency in the building (Chu 2009) (Jianyong Shi 2009). Similarly, Jiang et al. made simulations models for metro stations and transportation hubs so that the evacuation routes can be identified (Chuansheng Jiang 2009). The most important aspect of creating these models is to take in to account the behavior of people in an emergency situation so that the decision making can be precis (Peter B. Luh 2012) (Wei Lv 2013). Extensive research has also been carried out by using real-time data from different sensors for temperature and carbon monoxide to display the risk distribution so that real-time analysis of high rise buildings could be carried out (Zhuyang Han 2013).

2.9 Risk Identification and Assessment in Emergency Evacuation

A number of research papers were studied to identify the factors/problems in emergency evacuation whose results are as follows:

Table 2 – Factors / Problems identified through Literature Review

Factors / Problems	Research Papers									By-laws		Frequency
	A	B	C	D	E	F	G	H	I	J	K	
Need of Evacuation Plans	1	1	1	1	1	1	1	1	1	1	1	11
Knowledge of Evacuation Procedure	1	1					1					3
Exit Signs Clearly Visible		1			1		1			1		4
Exits Leads to Safety Area					1	1			1	1	1	5
Unrestricted Emergency Exits (Doors Unlocked)										1	1	2
Sufficient Exits of suitable Width	1	1		1	1		1	1	1	1	1	9
Enough Time available for Evacuation	1	1			1		1	1				5
Exit Door Swing Direction										1	1	2
Automatic Fire Detection and Alaram Systems	1	1	1	1	1	1	1			1		8
Need of Assistance while Evacuating	1	1	1		1	1	1		1			7
Fire Drills in last 3 months	1		1	1		1	1			1		6
Ease of using Evacuation Plans	1	1	1						1			4
Human Factor (Age)	1	1	1		1	1						5

Table 3 – Legend for Literature Review

Legend	
A	Application of building information modeling in designing fire evacuation-a case study (2014)
B	Applying building information modeling to support fire safety management (2015)
C	Building Emergency Plan, Hesse Hall, University of California (2016)
D	Fire Risk Assessment in High-Rise Hopitalls in Accordance With NFPA 101 (2018)
E	Optimization of egress controls of fire emergency management plans using agent based simulation: A case study of ready-made garment industry (2019)
F	Emergency Evacuation Operations Plan Architecture Hall Gould Hall & Community Design (2018)
G	Spatial analysis of buildings in relation to fire drills in RMG factories with special reference to emergency escape routes (2019)
H	A review of optimisation models for pedestrian evacuation and design problems (2016)
I	Assessment of Fire Escape Routes in Commercial High-Rise Buildings in the Nairobi CBD, Kenya (2015)
J	Building Code of Pakistan Fire Safety Provisions 2016 (Based on NFPA 1 Fire code 2015)
K	OSHA Emergency Action Plans, and Fire Prevention Plans in Title 29 of the Code of Federal Regulations (CFR)

These factors/problems were then confirmed by the survey questionnaire. A total of 99 responses were recorded. The probability and impact values were scaled from zero to four (0 – 4), with zero being null and four being highest. The average value obtained for probability and impact value is tabulated below:

Table 4 – Risk Assessment through Survey Questionnaire

Factors / Problems	Probability Scale (0-4)	Impact Value Scale (0-4)
Need of Evacuation Plans	3.61	3.00
Knowledge of Evacuation Procedure	2.75	2.77
Exit Signs Clearly Visible	3.41	3.20
Exits Leads to Safety Area	3.49	3.30
Unrestricted Emergency Exits (Doors Unlocked)	3.71	3.40
Sufficient Exits of suitable Width	2.95	3.00
Enough Time available for Evacuation	2.89	2.79
Exit Door Swing Direction	2.53	2.47
Automatic Fire Detection and Alaram Systems	3.06	2.91
Need of Assistance while Evacuating	3.16	3.05
Fire Drills in last 3 months	2.92	2.96

3. METHODOLOGY

3.1 General Overview

The following is the general methodology adopted for our project.

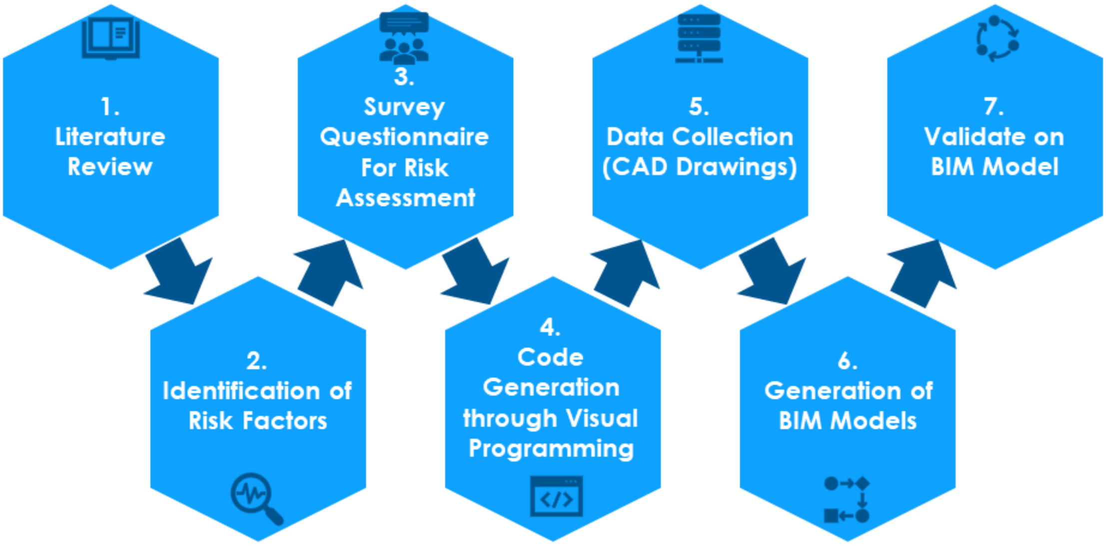

Figure 3 – Project Methodology

3.2 Data Collection

3.2.1 Fire Safety Provisions / Bye-Laws

The prevailing fire safety provisions/bye-laws were obtained from online free-access sources. Following fire safety provisions/bye-laws i.e. NFPA, OSHA, HSA, BCA & BCP were consulted. For the purpose with a major focus on BCP and NFPA.

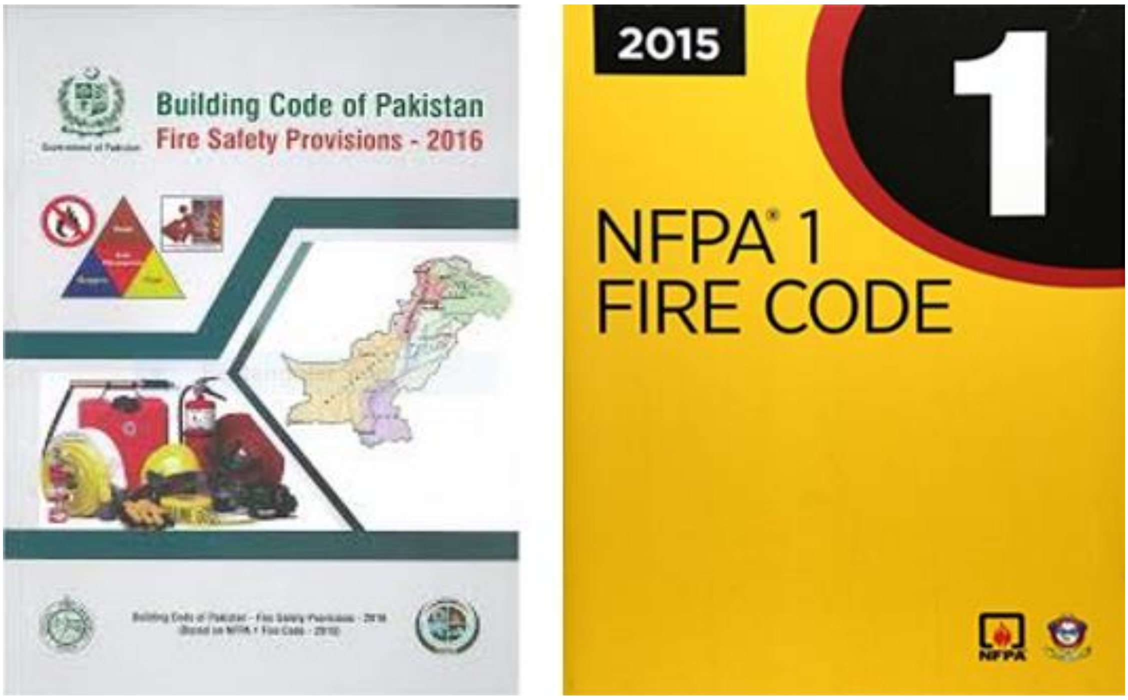

Figure 4 – BCP Fire Safety Provisions 2016 (Right), NFPA-1 Fire code 2015 (Left)

3.2.2 CAD Drawings

The CAD drawings of all the schools of NUST were obtained from the Project Management Office (PMO), NUST. These CAD drawings contained the architectural plans of the schools. In case of few schools, some data (such as elevations) was not available in CAD drawings, for those schools whose data was missing, trips were made to those schools, and required data was obtained by capturing photos (or whatever means necessary), so that parametric 3D BIM models could be developed. Moreover, there were discrepancies in the CAD drawings and actual school buildings, so trips were made to those schools and correct data was obtained so that accurate BIM models could be generated.

3.2.3 Survey Questionnaire

A survey questionnaire was created, and the survey was conducted throughout the NUST for the purpose of Risk Assessment. The survey questionnaire was based on the extensive literature review to check for provisions given in BCP (in compliance with NFPA) & OSHA.

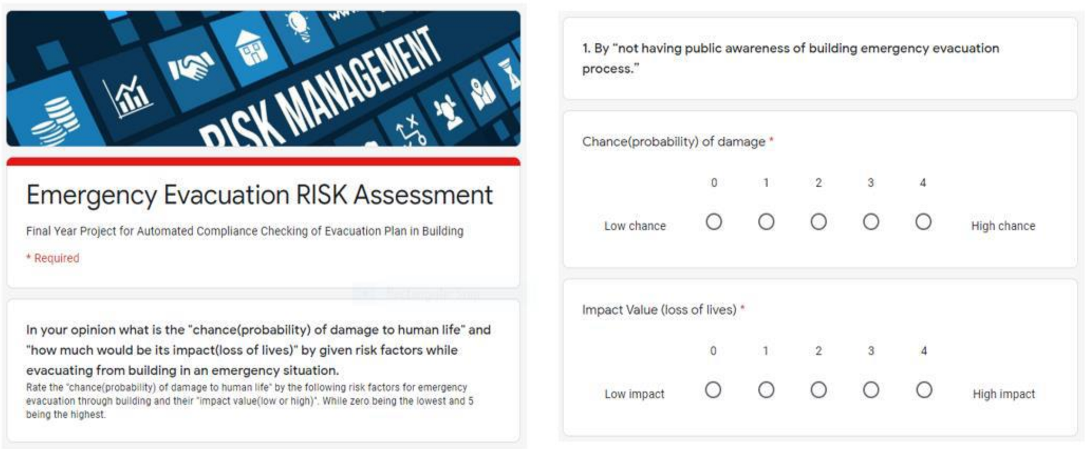

Figure 5 – Survey Questionnaire for Risk Assessment

3.3 BIM Models

After the successful acquisition for CAD drawing from PMO and collecting any missing data, parametric 3D model of a sample building of several NUST Schools/Institutes namely Atta-ur-Rahman School of Applied Biosciences (ASAB), Institute of Applied Electronics and Computing (IAEC), Institute of Environmental Science and Engineering (IESE), Institute of Geographical Information Systems (IGIS), NUST Institute of Civil Engineering (NICE), National Institute of Transportation (NIT), Research Center for Microwave and Millimeter-Wave Studies (RIMMS), School of Art, Design and Architecture (SADA), School of Natural Sciences (SNS), and School of Social Sciences and Humanities (S^3H) were developed using a BIM tool. In our project, we used Revit 2017 for the creations of these parametric 3D models.

Figure 6 – BIM model of Institute of Applied Electronics and Computing (IAEC)

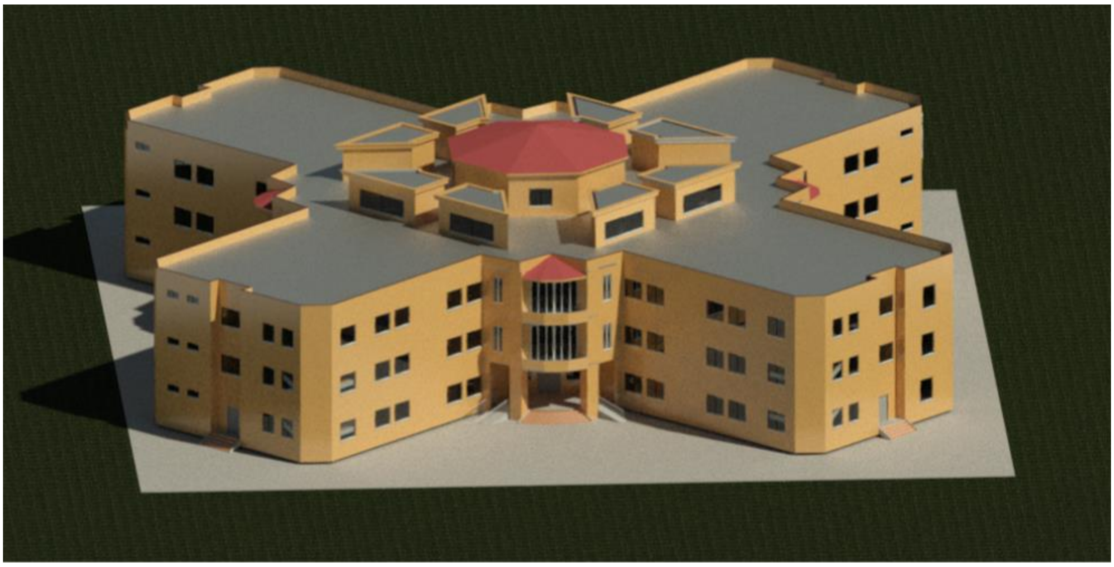

Figure 7 – BIM model of School of Art, Design and Architecture (SADA)

Figure 8 – BIM model of School of Social Sciences and Humanities (S^3H)

3.4 Process Development using Visual Programming

Process development for compliance checking and generation of evacuation was carried out using Visual Programming software. Two separate processes were developed, one for code compliance and one for the generation of evacuation plans. The process was generated using BIM-based visual programming. Once the process was created, it was tested on BIM models.

3.4.1 For Code Compliance

Before developing the process, the BCP Fire Safety Code was thoroughly studied and the codes that were related to emergency evacuation were extracted from it. These codes were then tabulated into a Microsoft Excel file. A process was developed to check these codes against the building using Dynamo Studio. Once the process was complete it was then tested on several BIM models.

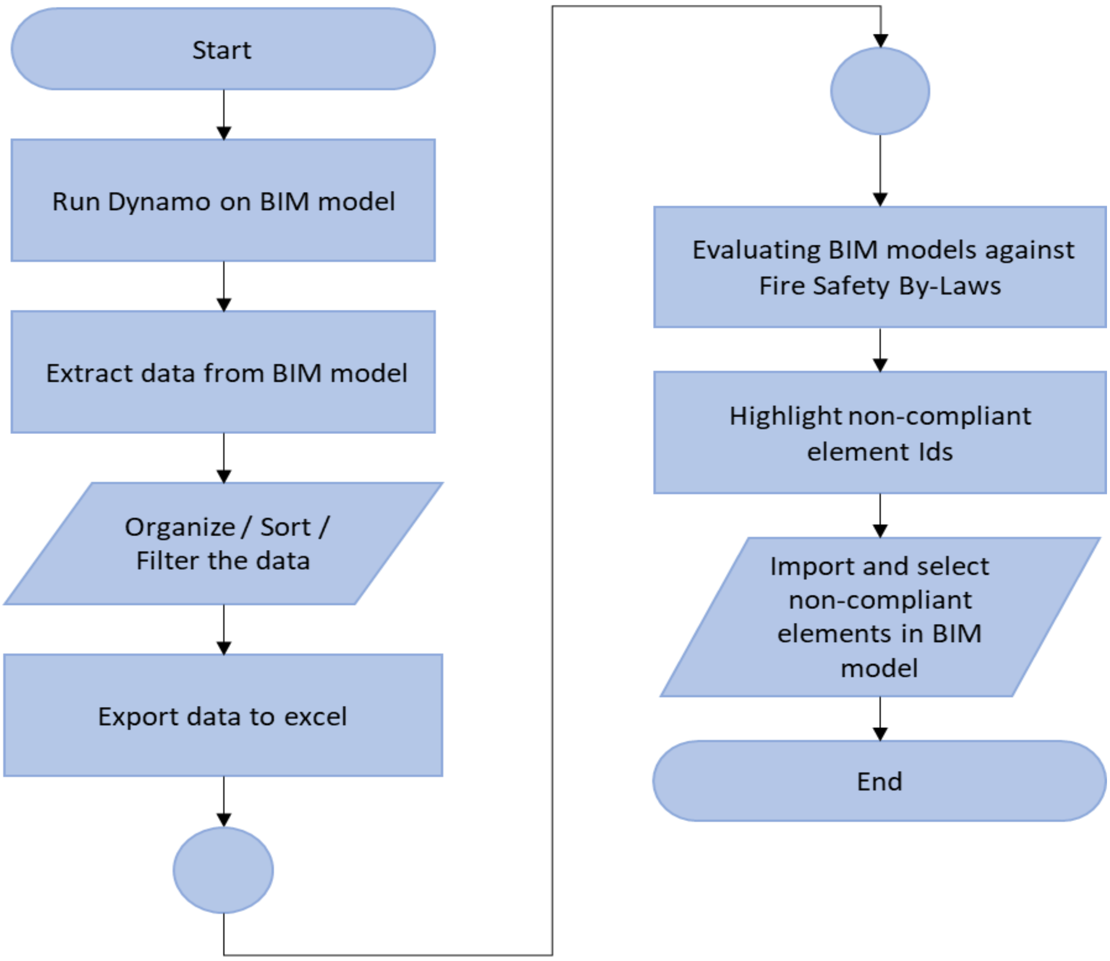

Figure 9 – Flowchart for Code Compliance Process

After the creation of an automated code compliance process, open the BIM Model in Autodesk Revit and run Dynamo. Assuming the 3D Model is a complete model i.e. it has well-defined rooms, tags, exit doors, evacuation doors, etc., Dynamo will extract data from the BIM model i.e. its features, specifications, and the dimensions.

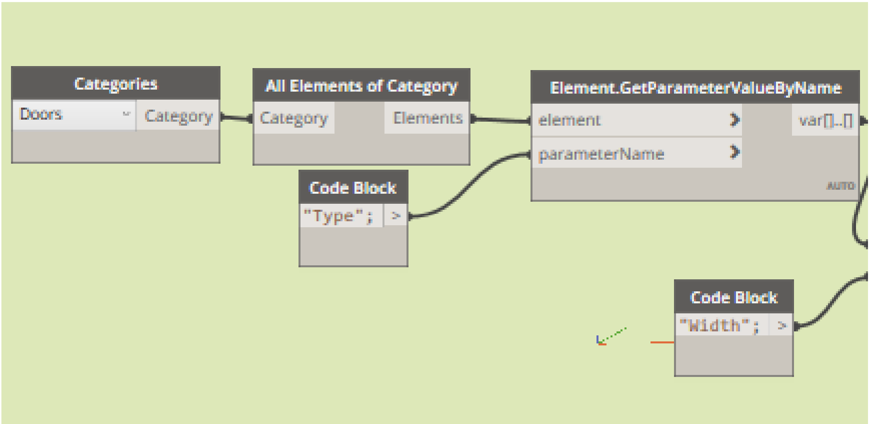

Figure 10 – Extracting Data from BIM Model

A typical BIM model has a lot of mixed-up data stored in it, but that jumbled up data is of no use in that form. So, the data extracted from the model is then organized, sorted, and filtered using nodes such as List, Transpose and Select, etc. The sorted and organized data is exported to excel where the further process of compliance checking is done.

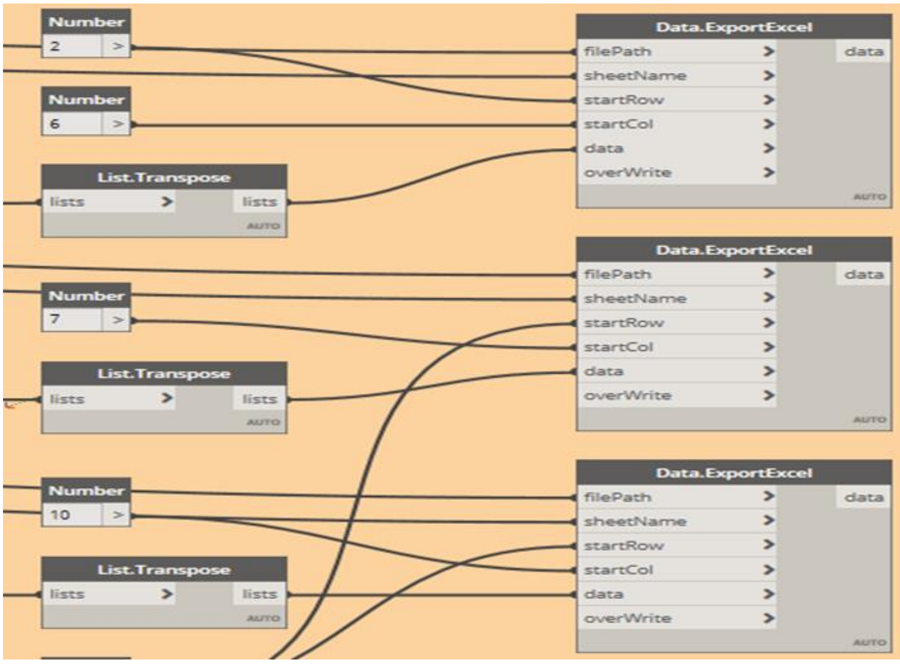

Figure 11 – Organizing and Filtering Data from BIM model

For the process of compliance checking, formulae are created in Microsoft Excel and different parameters of the 3D model are checked against the BCP Fire Safety Provisions. The extracted parameters are then compared with the fire safety codes, which will tell us what features comply, and which features do not comply with the fire safety codes.

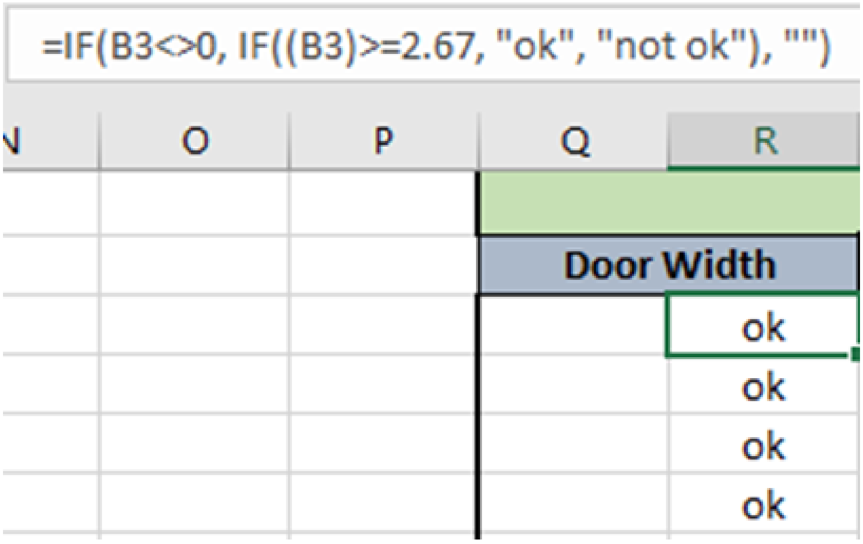

Figure 12 – Filtering data in Microsoft Excel

The features that do not comply are then highlighted in red and their element ids are extracted.

RESULTS						
	ID	Riser (ft)	Tread (ft)	Width (ft)	Risers /Flight	Angle ◦
	302548	not ok	not ok	ok	ok	ok
	305204	not ok	not ok	ok	ok	ok
	344243	not ok	not ok	ok	ok	ok
	425583	not ok	ok	ok	ok	ok
	463672	not ok	not ok	ok	ok	ok
	463998	not ok	not ok	ok	ok	ok

Figure 13 – Highlighting non-compliant elements

After that, those element ids are imported in Dynamo and are highlighted in the Revit model. In this step, first, all the non-compliant element ids are imported from Microsoft Excel (using Data Import node). Separate Lists are generated for each element type. Now the data is filtered to remove any irrelevant data and keep only non-compliant element ids (using Filter nodes). In the end, the elements are highlighted in the BIM model.

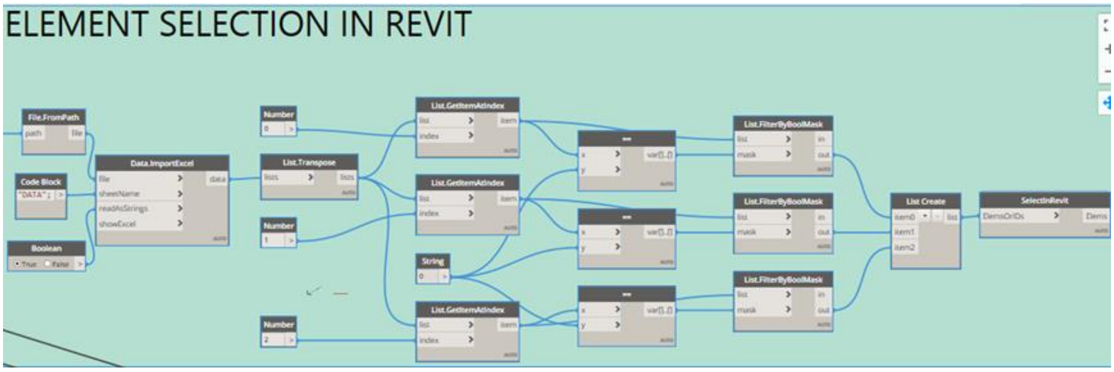

Figure 14 – Process flow for selecting non-compliant elements

To summarize the above step, in the first step open the BIM model and extract parametric data from BIM models (doors, stairs, etc.). In the next step, we filter, sort, and organize the extracted data (element ids, dimensions, etc.) and import it into Excel. In the next step, tabulate the BCP Fire Safety Codes in excel and generate formulae in Excel for Code Compliance. In the next step, highlight the non-compliant element ids. In the next step, a summary sheet and report are generated in Microsoft Excel. Lastly, the non-compliant element ids are imported and highlighted in the BIM model.

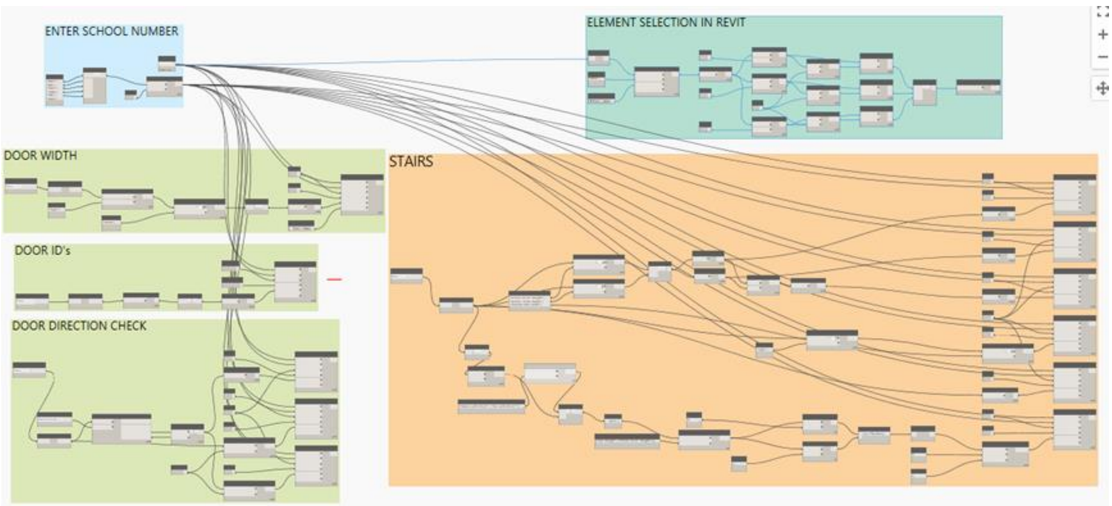

Figure 15 – Process Flow for Code Compliance process

3.4.2 For Generation of Emergency Evacuation Path

After the creation of an emergency evacuation path process, open the BIM Model in Autodesk Revit and run the Dynamo process. Assuming the 3D Model is a complete model i.e. it has well-defined rooms, tags, exit doors, evacuation doors, etc., Dynamo will extract data from the BIM model.

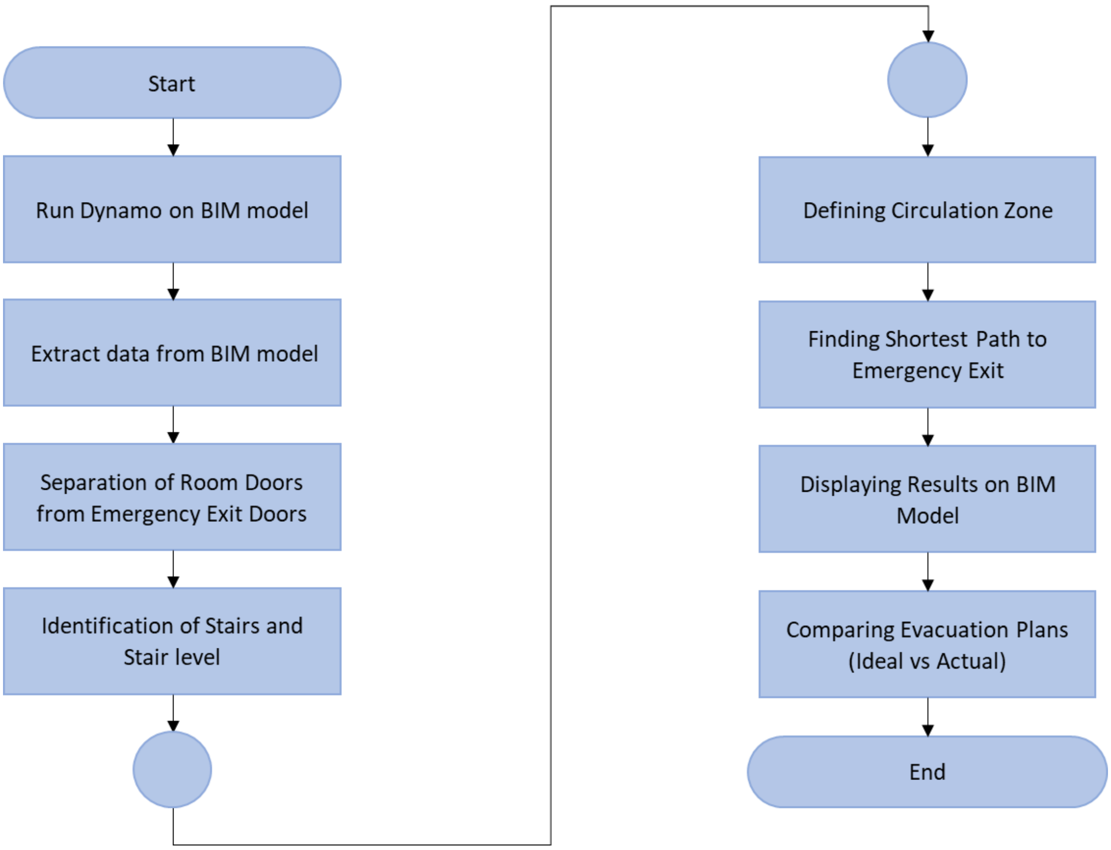

Figure 16 – Flowchart for Development of Emergency Evacuation Plans

Firstly, we will input the level on which the evacuation path is to be generated.

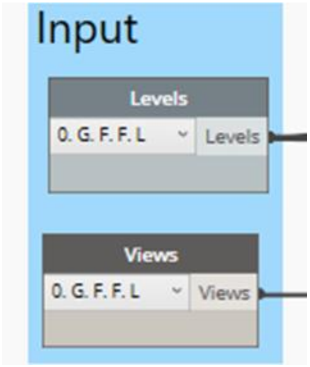

Figure 17 – Input Levels

Now extract all the doors (on the selected level) from the Revit model and then filter the Exit Doors from Room Doors. So, in this step, first of all, rooms and doors were given a parametric value/tags (e.g. room exits, emergency exit). Now Dynamo will extract elements (Doors) according to these parametric values (using Get Parameter node) and then these were filtered into Emergency Doors and Room Doors (using Filter node). Once elements were filtered, the location of the elements was obtained (using Get Location node) as shown below:

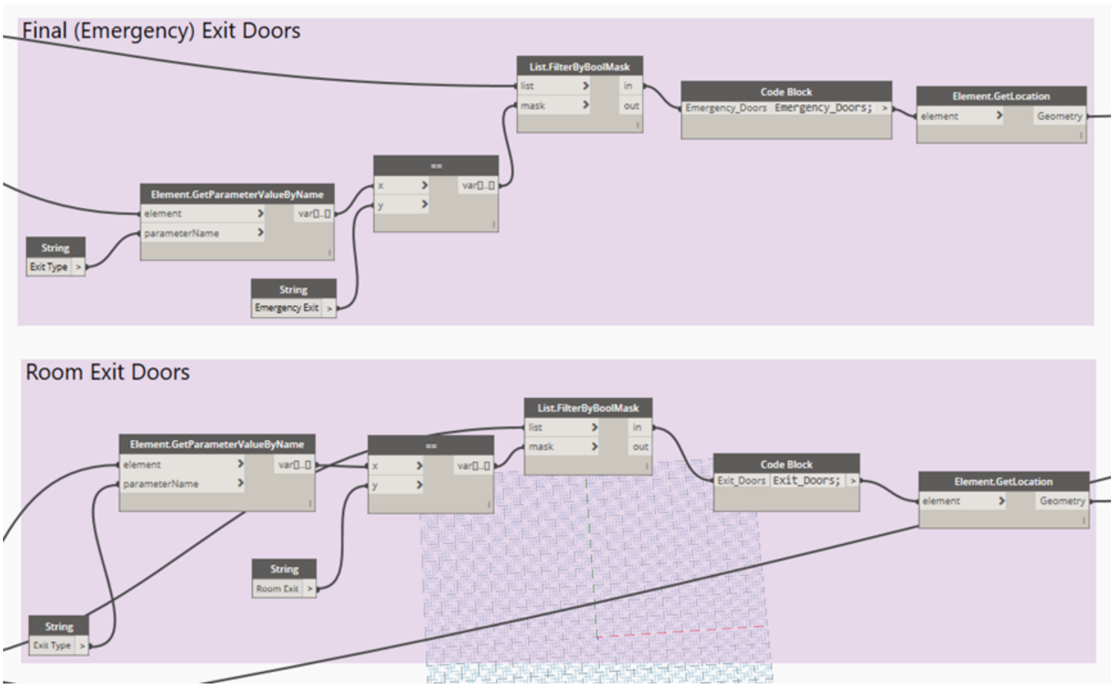

Figure 18 – Extracting and Filtering Exit Doors from Room Doors

The next step was to extract the location and levels of stairs. As stairs are structural members, so their location and level cannot directly be extracted like door elements in Dynamo. So, in this step, the first stairs are filtered (according to level on which we are generating evacuation path) based on their parametric value using Filter node. Now Risers of these stairs were filtered using Python Script (custom made node). Now, these stairs were converted into geometry (using Geometry nodes). Once converted into Geometry, the required points of the stairs are filtered according to the level on which the evacuation path is to be generated. This gives us the location of the stair's base and top points.

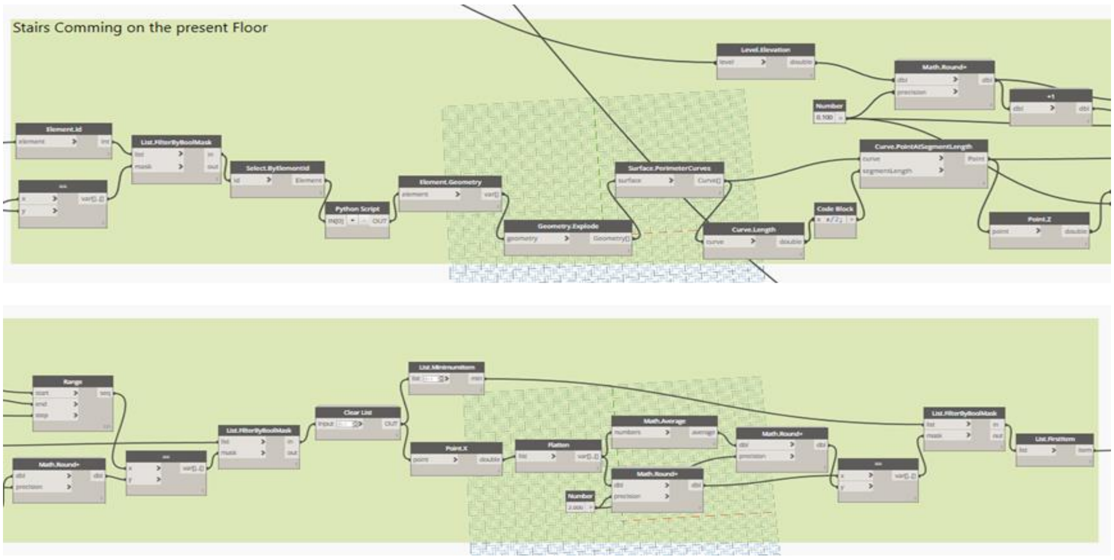

Figure 19 – Extracting Location and Levels of Stairs

After that, all the Rooms will be extracted and a Circulation Area where the evacuees can move is defined. It is done by eliminating the Room Area from the Total Area. In this step, first, the room tags are added to the BIM model. Now, these rooms are extracted (using Get Category node). Now the Room area will be filtered out from Total Area (using Filter nodes). This will eliminate the Room Area from Total Area and will give us the Circulation Area.

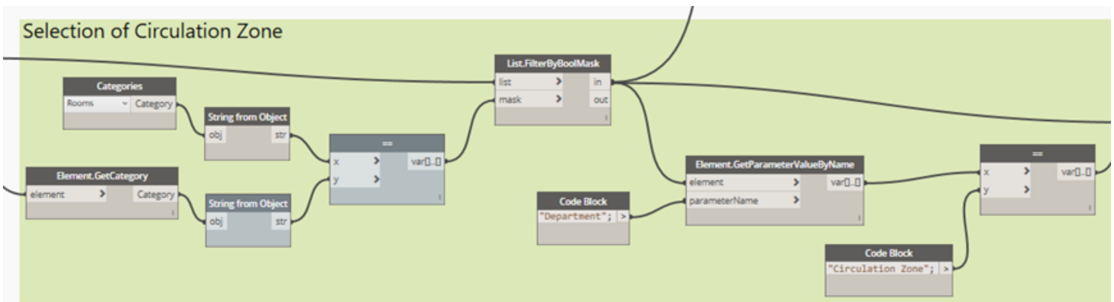

Figure 20 – Extracting Circulation Area from Total Area

Once the Circulation Area is extracted, now the boundary of this area is defined, and it is converted into the surface. And intersecting curves are drawn on the surface, which will then be used to determine the shortest path.

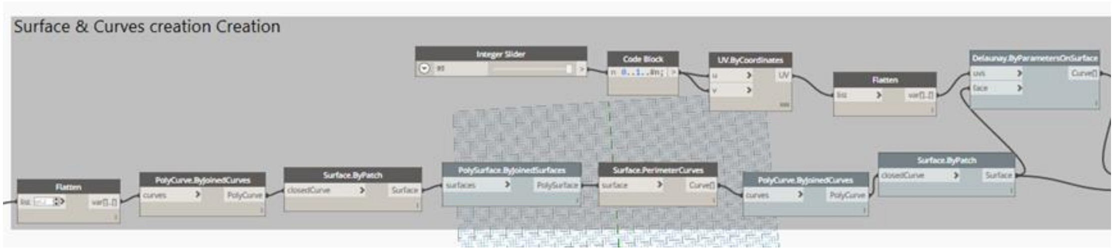

Figure 21 – Converting Circulation Area into Surface

Once the Circulation Surface is generated, the shortest path is defined between the Room Doors, Stairs, and the Emergency Exits. In this step, first straight lines are drawn between Room Exits and Emergency Exits. Now the curves (which were created in an earlier step) are filtered, which are following these straight lines. This will give us multiple lines, leading to the Emergency Exits. From these lines, the one with the shortest distance to the Emergency Exits will be selected. The same steps will be followed to create lines between stairs and Exits.

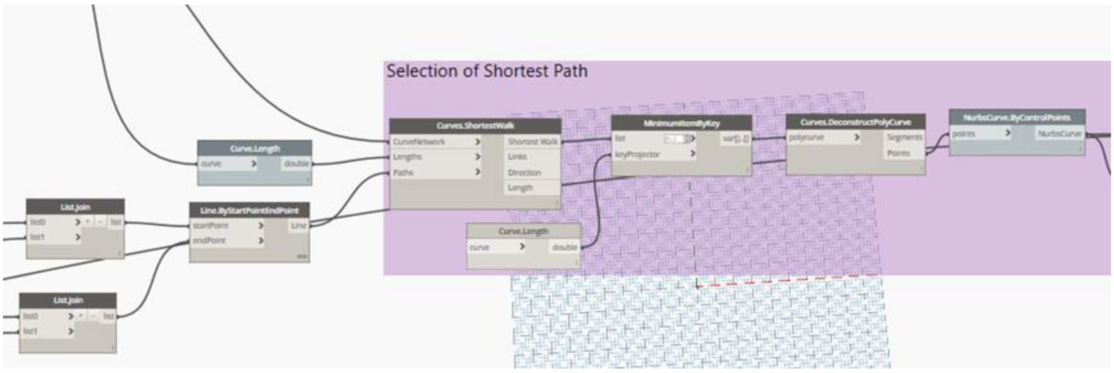

Figure 22 – Generating Shortest Route

In the end, the shortest path is shown in the BIM model. In this step, the shortest path obtained in the earlier step is assigned properties such as Line Type, Line Weight, Color, etc. and finally are displayed in the BIM model.

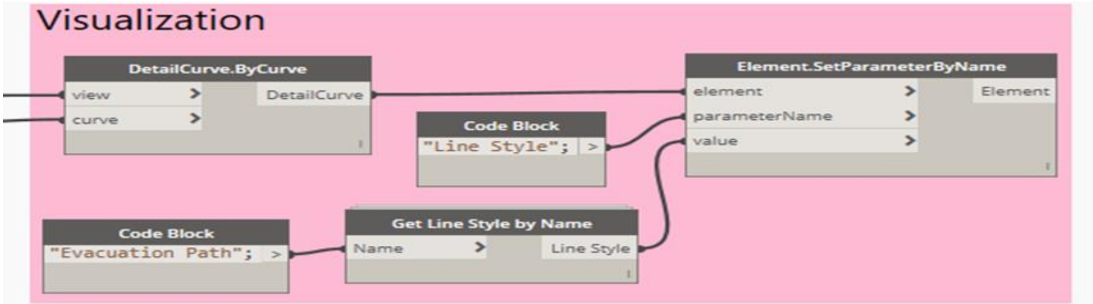

Figure 23 – Display Evacuation Path on BIM Model

To summarize the above step, in the first step input the level on which the evacuation path is to be generated. In the second step, extract all the doors (on selected level) from the Revit model and then filter the Exit Doors from Room Doors. In the third step, extract the location and levels of stairs. In the fourth step, the Rooms will be extracted and a Circulation Area where the evacuees can move is defined. It is done by eliminating the Room Area from the Total Area. In the fifth step, the Circulation Area is converted on a surface. In the sixth step, the shortest path is defined between the Room Doors, Stairs, and the Emergency Exits. In the last step, the shortest path is shown on the BIM Model.

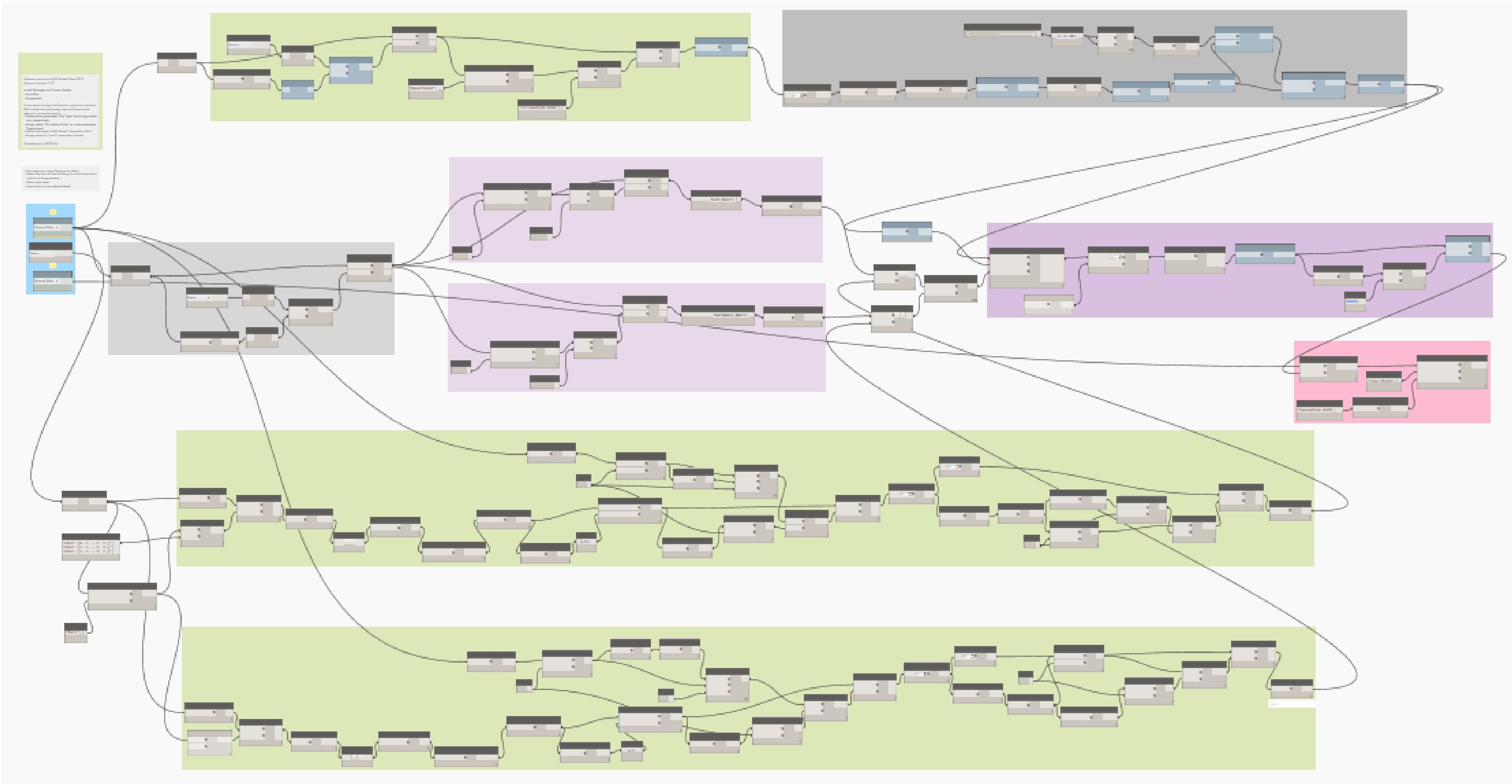

Figure 24 – Process Flow for Generation of Evacuation Paths

Chapter 4

4. RESULTS

4.1 Background

To identify and assess the present risks in the building for emergency evacuation, literature was studied, and a survey was conducted. For the purpose of creating the Automated Code Compliance checking process and generation of emergency evacuation paths, several BIM models of NUST Schools were created using Autodesk Revit 2017 and were used for testing the process which was developed using Dynamo Studio.

4.2 Generation of BIM Models

A complete parametric BIM model was successfully created (as shown below), and both the processes were subsequently tested on it.

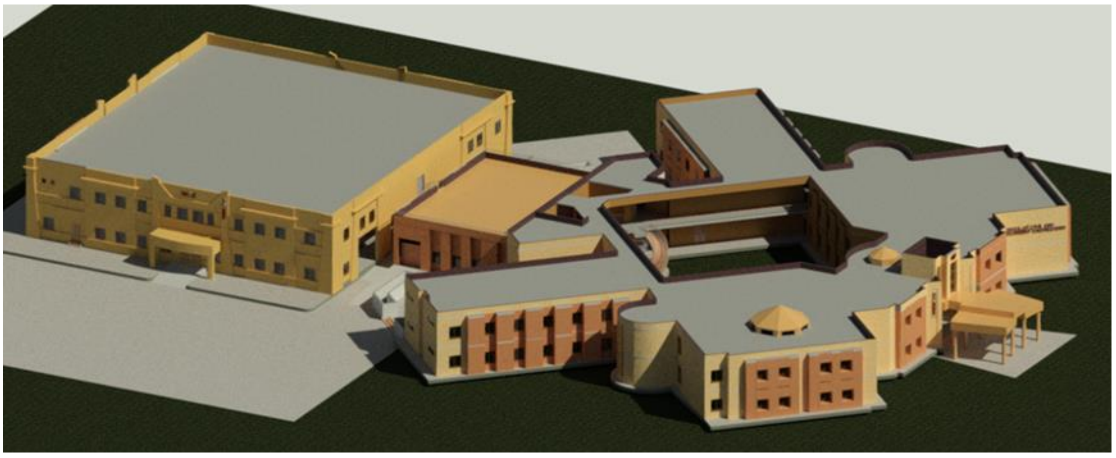

Figure 25 – Parametric BIM Model of NICE and NIT

4.3 Generation of Code Compliance Process

A report is generated in Microsoft Excel which checks for the Code Compliance and tells if the element is “ok” or “not ok”. The elements that are non-compliant, their element ids are displayed and are highlighted.

RESULTS									
Door Width		Exit Door Direction		Element ID	Riser (ft)	Tread (ft)	Width (ft)	Risers /Flight	Angle °
Element ID	Check	Element ID	Check		Check				
	ok	313070	not ok	328045	not ok	ok	not ok	not ok	ok
	ok		ok	333109	not ok	ok	not ok	not ok	ok
	ok		ok	341104	not ok	ok	not ok	not ok	ok
	ok		ok	374463	ok	ok	not ok	ok	ok
	ok		ok	375716	ok	ok	not ok	ok	ok
	ok		ok	376062	ok	ok	not ok	ok	ok
	ok		ok					ok	
	ok		ok					ok	
	ok	323782	not ok					ok	
	ok	323848	not ok						
	ok		ok						
	ok		ok						
	ok		ok						
	ok		ok						
	ok		ok						
324858	not ok		ok						
324919	not ok		ok						
324996	not ok		ok						
325036	not ok		ok						

Figure 26 – Code Compliance in Microsoft Excel

Further, in a new sheet, a summary is created that shows the element ids of the non-compliant element only.

NON COMPLIANCED ELEMENT ID's		
Door Width	Exit Door Direction	Stairs
417399	433306	463998
417371	367069	463672
417339	343154	425583
417294		344243
417081		305204
417043		302548
417003		
416918		
334035		

Figure 27 – Summary of non-compliant element ids

And lastly, non-compliant elements are also highlighted in BIM models as shown below:

Figure 28 – Non-compliant elements highlighted in BIM model (doors)

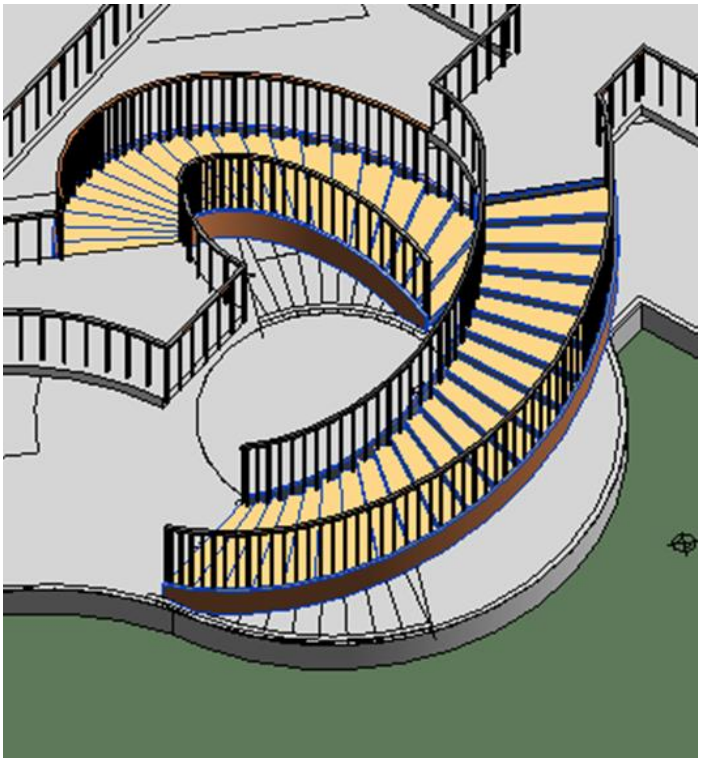

Figure 29 – Non-compliant elements highlighted in BIM model (stairs)

4.4 Generation of Emergency Evacuation Path

Evacuation paths were developed in two scenarios, first is ideal conditions in which all emergency exits are opened and second is actual conditions in which some or all emergency exits locked.

4.4.1 Evacuation Path in Ideal Condition

Following is the evacuation path that is generated when there are no restrictions in emergency exits (i.e. all emergency exits are opened).

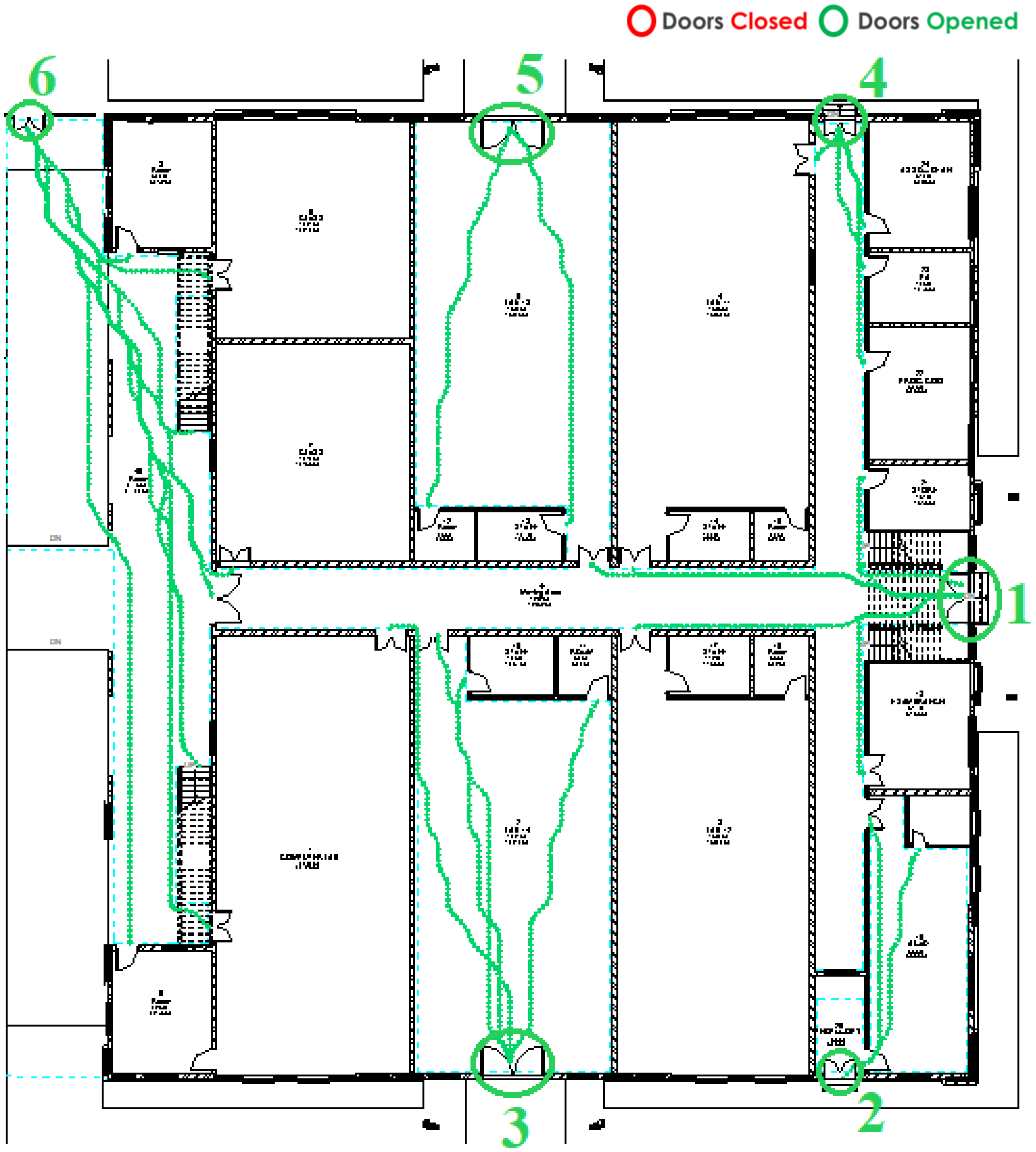

Figure 30 – Evacuation Plan for NICE in Ideal Condition

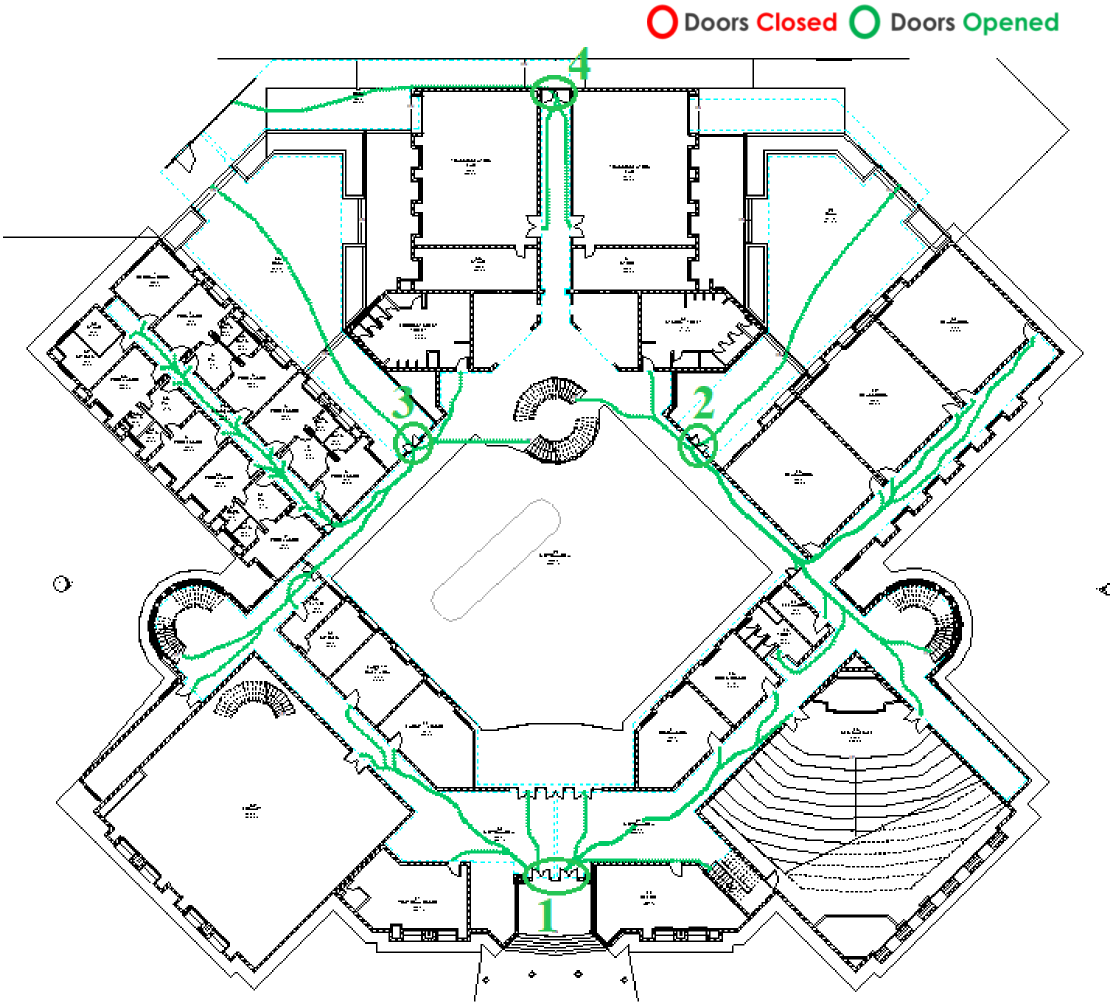

Figure 31 – Evacuation Plan for NIT in Ideal Condition

4.4.2 Evacuation Path in Actual Condition

Following is the evacuation path that is generated when there are restrictions in emergency exits (i.e. some or all emergency exits locked).

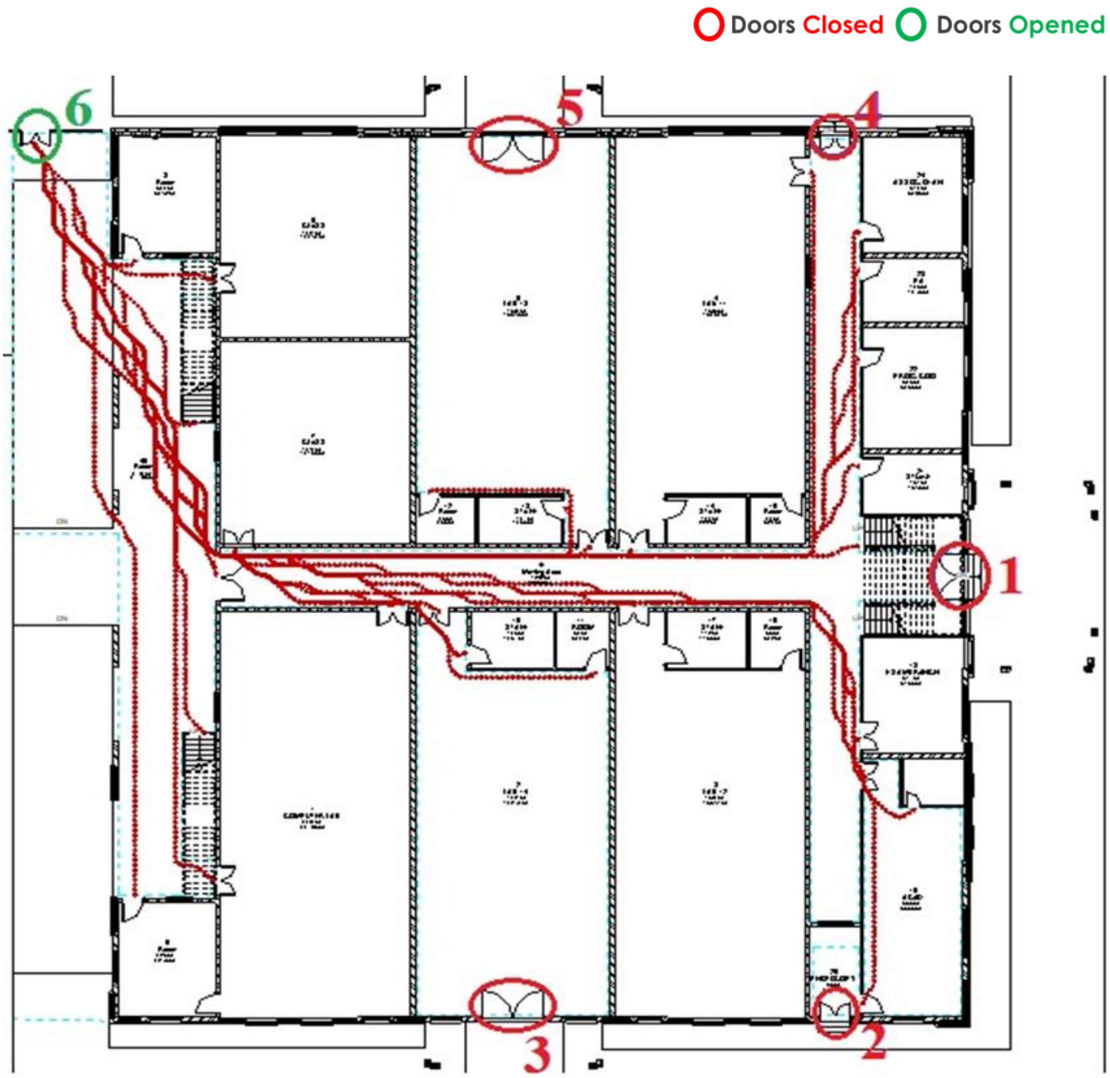

Figure 32 – Evacuation Plan for NICE in Actual Condition

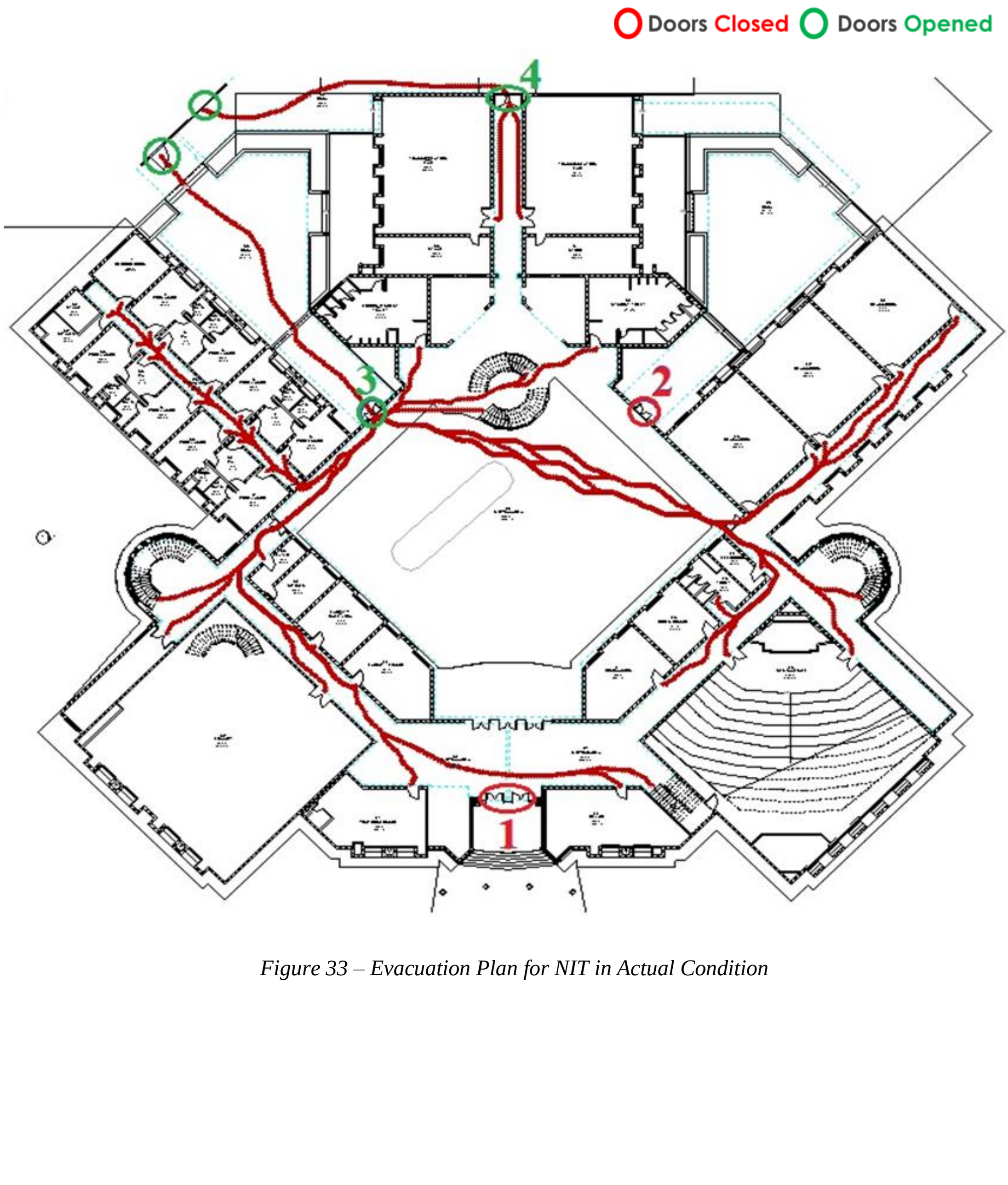

Figure 33 – Evacuation Plan for NIT in Actual Condition

4.4.3 Comparison between Ideal Condition vs Actual Condition

Following is a brief comparison between the ideal conditions and actual condition:

- When all emergency exits are open people are directed towards their nearest exits. In this way, people will get out of the buildings in less time and it is less likely that any bottlenecks will be generated.
- On the other hand, When the emergency exits are closed, people are directed towards only one or two emergency exits that are open. This will not only increase the time to evacuate the building but also will create a bottleneck effect on the emergency exits.
- As can be seen in the model of NICE that when the emergency exits are closed, all evacuees are directed towards a single corridor. The corridor can easily get congested and a bottleneck will be generated at the end of the corridor, and in case of emergency, when there is a sense of chaos, this could lead to an increased threat to human safety.

Chapter 5

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

After the successful creation of a process for code compliance and generation of evacuation path, it was tested on several 3D BIM Models, and from it following can be concluded:

1) The Automation of Code Compliance removes the chances of human error from the compliance checking process.
2) As Code Compliance is a laborious and time taking process, automating it saves a lot of time and effort. The work of days can be done in minutes or hours.
3) Efficient Emergency Evacuation plans for buildings can be generated in a matter of minutes, saving both the effort and time.
4) Enhances the capability of existing software to achieve the true benefits of BIM technology.
5) By providing an efficient evacuation path to the users in need, a lot of precious human lives could be saved.
6) A comparison between ideal conditions and actual conditions for evacuations can be done, which helps in analyzing the potential bottlenecks.
7) Once the comparison is done, remedies can be made to avoid potential bottlenecks.

5.2 Recommendations

Due to the prevailing pandemic Novel Coronavirus (COVID-19) and limited availability of time and resources, the scope of this project was limited. However, there are many research opportunities that can be explored.

5.2.1 For other Building Codes

For the scope of this project, the BCP – Fire Safety Provisions (2016) was used only. However, the process can be amended according to different building codes and bye-laws prevailing in different countries.

5.2.2 For other Building Types

For the purpose of this project, the evacuation compliance checking was conducted for Educational buildings only (NUST Schools). However, with few amendments to the process, evacuation compliance checking can be conducted for Commercial, Institutional, Business, Industrial, Multi-Storey or High-Rise Buildings too.

5.2.3 Real-Time Emergency Evacuation

The scope of this project can be greatly increased by using modern technologies like RFIDs and Bluetooth routing etc. which can be used to display real-time evacuation paths on the end-user smartphones using the mobile application. Such an application can help save hundreds of lives in case of emergency in buildings.

5.2.4 Accessibility on Autodesk App Store

With the help of programming, freeware or paid application can also be created on the Autodesk App Store. But for that purpose, the process must be flexible to accommodate the different requirements in different countries.

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