A BIM-Based Framework for Code Compliance Audit of Universal Accessibility Design Requirements

By

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This thesis is dedicated to the members of the paraplegic community and to the pursuit of creating a universally accessible environment

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ABSTRACT

The study aims to enhance the Universal Design evaluation process by leveraging Building Information Modelling (BIM) to automate accessibility assessment for buildings. With a growing aging population, increased disability prevalence, and the necessity to accommodate diverse travelers, Universal Design Evaluation gains importance. However, traditional manual evaluation methods exhibit errors. BIM, as a comprehensive 3D model incorporating building information, offers a practical alternative for assessing universal accessibility. This study proposes a framework utilizing BIM to measure accessibility in both existing and new building plans, aiming to ensure Universal Design principles are incorporated. By automating accessibility assessment through Dynamo using BIM data during the design stage, can potentially lead to significant reductions in time and labour for review, enhancing the proficiency of the evaluation process. Additionally, BIM facilitates early identification of accessibility issues, minimizing adverse effects of design changes during construction. The transition to automated BIM-based checking systems not only streamlines the design approval process but also promotes transparency within the Architecture, Engineering and Construction (AEC) business, signalling positive advancement in Universal Design implementation. Persons with disabilities (PWD) constitute a significant portion of society, necessitating comprehensive support, including accessible environments, and full inclusion in all spheres of life. Despite existing accessibility codes, the absence of an accessible system for PWD highlights systemic challenges. Automated code checking emerges as a critical phase in the design and construction process, requiring standardization and technological advancements. By integrating Universal Design and BIM, the study seeks to optimize accessibility and minimize the need for future renovations, emphasizing the necessity of automation and digitalization in enhancing inclusivity and efficiency in architectural design and construction processes.

.**Keywords**:Universal Design; Building Information Modelling (BIM); Accessibility assessment; Persons with disabilities (PWD); Automated code checking; Accessibility codes; Architectural design efficiency; Universal Design

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYM

UD	Universal Design
2D	Two-Dimensional
BIM	Building Information Modeling
3D	Three-Dimensional
AEC	Architecture, Engineering, and Construction
SDG	Sustainable Development Goal
CRPD	Convention on The Rights of Persons with Disabilities
LEED	Leadership in Energy and Environmental Design
USGBC	US Green Building Council
UN	United Nations
UNDP	United Nations Development Programme
ADAAG	Americans with Disabilities Act Accessibility Guidelines
MEP	Mechanical, Electrical, and Plumbing
API	Application Programming Interface
ASCE	American Society of Civil Engineers
PWD	People with Disabilities
RII	Relative Importance Index
ANOVA	Analysis of Variance.

CHAPTER 1:INTRODUCTION

1.1 Brief Description

The objective of this study is to augment the assessment procedure for Universal Design by examining the current guide for evaluating Universal Design in buildings and exploring the automated approach to evaluation. The increasing elderly population, growing number of individuals with disabilities, and the necessity to accommodate foreign visitors have contributed to the rising popularity of Universal Design Evaluation (Carr et al., 2013; United Nations, 2022). Consequently, contributed significantly to the advancement of architectural design and development rooted in the principles of Universal Design.

However, the current 2D drawing method has many errors (Demir Altıntaş & Ilal, 2021; Wu, Akanbi, et al., 2022), and the diversity in shapes of multi-purpose buildings has led to a rise in several items required for evaluation. This has led to more time and labour needed for the review (Jiang et al., 2022; Xue & Zhang, 2022).

The integration of three-dimensional (3D) models encompassing various aspects of building information, including construction costs, processes, materials, and specifications, constitutes Building Information Modeling (BIM). Its purpose is to effectively incorporate, generate, direct, and utilize the data in every part of the construction operations (Al-Ashmori et al., 2020). In the realm of assessing universally accessible design, BIM has emerged as a practical alternative to the conventional two-dimensional (2D) drawing method (Sampaio et al., 2023). The objective of this research is to establish an outline that employs BIM in order to evaluate accessibility of the existing and new building plans (Yu & Choi, 2023). The goal is to incorporate Universal Design, and suggestions will be provided to achieve maximum accessibility if it is not already incorporated (Sun & Kim, 2022). The utilization of Building Information Modeling (BIM) data in the design phase enables the automatic assessment of building accessibility, resulting in a significant reduction in the time and effort needed for the review process (Y. C. Lee et al., 2015). Additionally, this method boosts the evaluation method of Universal Design and enhances the efficiency of both designers and reviewers. Moreover, the implementation of Building Information Modeling (BIM) can play a crucial role in pre-emptively recognizing any possible accessibility concerns prior to the construction phase beginning, thereby mitigating the negative impacts of design alterations during the construction process. Consequently, the automation of the evaluation of universal accessible design can significantly enhance the overall efficiency and efficacy of the assessment procedure (Nawari, 2019).

1.2 Reasons / Justification for Selection of The Topic:

According to Nawari (2012) professionals write rules and regulations so people can read, interpret, and apply them. Currently, these design and construction documents are manually assessed against a constantly evolving, progressively complex arrangement of building codes when submitted for permitting to the governing body (Greenwood et al., 2010), which is both laborious and resource-consuming (Y. Chen et al., 2022). Automating this process poses a significant challenge to the Architecture, Engineering, and Construction (AEC) industry, which raises question of how to carry out computerisation of this process successfully (Nawari, 2012).

Valdez (2012) advocates for designing homes with greater accessibility to enhance the comfort, safety, and well-being of the occupants, especially seniors. Jrade & Valdez (2012) suggests that designers use tools to develop 3D models that meet Universal Design (UD) requirements for the built-in database. This would facilitate designers' and construction companies' application of UD principles to their buildings and future homes.

By implementing an automated BIM-based checking system, expenditures on calculations, printing, transportation, extra meetings, and staff compensation could be significantly reduced, if not eliminated entirely (Arendsen et al., 2014). An open platform for architects, engineers, and relevant authorities provided by the automated BIM-based checking system ensures transparency in the design and approval process. This step forward represents a positive development for the AEC industry (Gu & London, 2010).

1.3 Objectives:

i. To analyse the inefficiencies in code compliance of Universal Accessibility Design

ii. To develop a framework for a BIM-based automated Accessibility Design Assessment.

iii. To realise the framework using a case study.

1.4 Relevance to National Needs

This study targets to improve the well-being, safety, public health of individuals with disabilities by implementing an automated BIM-based checking system. A significant portion of the population has some form of disability that impairs their ability to navigate and use their surroundings. These individuals can only move and use their environments easily; their full participation and equality can be achieved. The primary focus is on ensuring safe and convenient access for individuals having infirmities in public places and buildings (PEPAC, 2007). This will facilitate the integration of universal design in buildings, allowing individuals having disabilities to live actively and independently. Furthermore, this will contribute to the realization of Sustainable Development Goal (SDG), specifically Goal 10, which seeks to foster equality both within and among nations. Target 10.2, as outlined by the United Nations (2015), emphasizes the imperative to enable and advocate for the economic, social and political attachment of all individuals, irrespective of gender, age, disability, origin, , race, religion, ethnicity or socioeconomic class, by the year 2030.

1.5 Advantages:

- The digital prototype of the framework for a BIM-based automated design checking system will ensure transparency in the design and approval process.
- Equality of opportunity will be achieved through architecture among differently-abled people.
- Inclusiveness in Designing spaces will encourage acceptance of differently-abled persons in the community.
- Automation of application of Pakistan’s standards for accessible design.

1.6 Area of Application:

This research has an area of application in residential buildings and city development authorities, and it can be extended to commercial and public buildings.

CHAPTER 2:LITERATURE REVIEW

2.1 Construction Industry

Throughout its extensive history, the construction industry has heavily relied on conventional techniques that have undergone continuous refinement and transmission from one generation to the next. However, conventional methods are still in use despite their potential drawbacks, including being time-consuming, labour-intensive, and inefficient (Greenwood et al., 2010). It is crucial for construction professionals to stay informed about new construction technologies and methods and to evaluate them against traditional methods to determine the best approach for each project (Chan et al., 2016).

Construction projects are highly collaborative and involve various entities, such as designers, clients, contractors, and consultants from both the private and public sectors (W. Tan, 2015). Therefore, the traditional practice of evaluating design work after completion may not be beneficial (X. Tan et al., 2010). platform The field of computer science has exerted a considerable influence on the advancement of the industry, compelling its adoption of novel technologies and methodologies, thereby leading to notable enhancements in efficiency, output quality, and productivity (Greenwood et al., 2010). A prime illustration of this impact is evident in the advent of Building Information Modeling (BIM) as a groundbreaking potential instrument, within the construction sector, facilitating seamless collaboration among stakeholders on a unified platform (Honic et al., 2019).

2.2 Building Code Compliance in the Construction Industry

According to the Penn State Libraries, building codes establish the minimum standards for constructing buildings to ensure the public's safety, health, and general welfare about structures' design, construction, and occupancy.

Our physical spaces are purposefully constructed according to guidelines that protect our safety and promote our overall welfare (Dimyadi & Amor, 2013). This involves reviewing building plans against a set of building regulations that are continually evolving and becoming more intricate (Greenwood et al., 2010). The complex set of building regulations, also called Building codes, have legal enforceability and carry established penalties for non-adherence. According to Roos (2019), individuals who fail to comply with building codes, including builders, designers, or owners, may face consequences such as making necessary repairs, ceasing construction activity, withdrawing their building permit, demolishing some or all portions of the work, and paying fines. Buildings that do not meet code requirements may pose serious safety risks, and current building codes aim to ensure building safety, resiliency, and efficiency (Nawari, 2012).

Building designs are manually assessed for conformity with national codes (X. Tan et al., 2010). According to Nguyen (2005), manual checking is a conventional method in which design evaluation is typically conducted after all the design tasks for the building have been finished. Alhosan & Zhang (2017) further argues that manual evaluation becomes redundant and repetitive, resulting in protracted, costly, and erring fallible process. Evaluating compliance is a significant responsibility for both architects and building certifiers, and it frequently entails assessing ambiguous and inconsistent criteria, which can result in construction delays (Macit & Günayd, 2017). The sheer volume of project information and design criteria that participants or evaluators must consider can overwhelm them, leading to mistakes or oversights in the evaluation (Nwadike et al., 2021). Automated compliance checking could be a beneficial solution to address this issue. Multiple studies have demonstrated that the implementation of automated compliance checking has the potential to significantly decrease the time needed for compliance checking, all the while enhancing its precision. It further enhances collaboration among stakeholders in the construction industry (Greenwood et al., 2010).

2.3 Code Compliance and The Need for Accessibility

Building codes have been around for nearly 4,000 years (Ching et al., 2018). As part of the design process, a building undergoes several regulatory compliance evaluations throughout its lifespan (Dimyadi & Amor, 2013). Compliance evaluation guarantees the public's well-being and safety and establishes the basis for design professional licensing and the justification for building regulations. (Ching et al., 2018; Dym et al., 1988).

The concepts of "inclusive design" , "universal access," and "design for all," refer to diverse methods that primarily address improving the ease of access of collaborating systems to adapt a wide range of consumers (Persson et al., 2015). Recently, an increasing emphasis on ensuring accessibility for everyone, with a particular emphasis on providing equal options for all people to fully take part in the society has been observed (Pratiwi, n.d.). Nations (2007) the Convention on The Rights of Persons With Disabilities (CRPD) highlights the objective of accessibility as empowering individuals having infirmities to live their life with independence and actively. Alhosan & Zhang (2017) provide guidance on identifying and eliminating barriers to ensure that people having disabilities have the same access to the constructed surroundings like their non-disabled counterparts. This includes a variety of locations, including structures, roads, transportation, and indoor and outdoor facilities.

The purpose of the accessibility code's design is to offer identical or equivalent access to buildings and their amenities for individuals with disabilities (Han et al., 1998), in addition to accommodating them into society and enabling them to play an active role and lead a typical life (Ibrahim Badawy et al., 2020). The United Nations has assembled in one place different Disability Laws and Acts as per Country. Some of the commonly referenced building standards for people with disabilities are as follows:

1. **Americans with Disabilities Act (ADA) Standards for Accessible Design**: The accessibility standards set by the US Department of Justice for public accommodations along with commercial facilities. These standards cover everything from doorways and entrances to restrooms and parking lots.
2. **International Building Code (IBC)**: The International Building Code (IBC) is a compilation of model construction codes set by the International Code Council (ICC) that outlines the fundamental criteria for constructing safe and accessible buildings. The IBC's accessibility requirements are designed to align with the standards specified by the Americans with Disabilities Act (ADA).

3. **International Organization for Standardization (ISO) 21542:2011**: This is a global standard for building accessibility that guides the designing and constructing buildings accessible to people with disabilities.
4. **Disability Discrimination Act (DDA)**: An Australian law that prohibits discrimination based on a person's disability. DDA has had a substantial influence on improving the life quality of individuals having disabilities and fostering a more inclusive societal framework within the Australian context.
5. **Equality Act 2010**: The Disability Discrimination Act (DDA), which was initially implemented in the United Kingdom, underwent subsequent replacement with the enactment of the Equality Act 2010. The DDA was a landmark piece of legislation in the UK, helping to promote greater inclusivity and accessibility for people with disabilities. The act has since been replaced by the Equality Act 2010, which extends protections against discrimination to other groups based on age, gender, and sexual orientation, in addition to disabilities.
6. **Accessibility Code of Pakistan 2006**: The Accessibility Code of Pakistan 2006, a comprehensive set of regulations established by the Government of Pakistan, is a testament to their commitment to promoting accessibility and inclusivity for people with disabilities. According to this regulation, it is required that all newly constructed buildings and facilities, encompassing public structures, commercial establishments, and residential properties, must be planned and constructed in a manner that enables individuals with disabilities to access them. The code specifies detailed guidelines for the design of ramps, elevators, toilets, parking spaces, and other features, ensuring that they are accessible to individuals with various disabilities.

7. **Persons with Disabilities (Equal Opportunities, Protection of Rights and Full Participation) Act**: The regulation encompasses a variety of strategies intended to nurturing the integration and engagement of persons having disabilities within the fabric of Indian society.
8. **Act on the Elimination of Disability Discrimination**: In order to foster the inclusion and active involvement of individuals with disabilities within Japanese society, efforts are being made to promote their rights and participation. The act requires public buildings, transportation systems, and other facilities to be accessible to people with disabilities.
9. **Disability Discrimination Act:** In South Africa, the Promotion of Equality and Prevention of Unfair Discrimination Act, frequently denoted as the Equality Act, is a law that prohibits discrimination in various domains, such as disability.
10. **Canadian Human Rights Act**: The act prohibits discrimination on various grounds, including race, nationality, ethnicity, religion, age, gender, and disability.
11. **Convention on the Rights of Persons with Disabilities (CRPD):** In 2006, the global community came together in support of this significant agreement, which was officially adopted via the United Nations General Assembly. Known as the CRPD, it stands out as the inaugural human rights agreement of the millennium that specifically focuses on the rights and requirements of individuals with disabilities. Its impact has been far-reaching, with more than 170 nations affixing their signatures to this historic document, solidifying its status as the most universally endorsed human rights agreements to date. The CRPD includes a range of rights, including the right to education, work,

health, and social protection. Among its provisions, the document includes requirements for accessibility, mandating that nations implement measures to ensure individuals with disabilities have admittance to corporal spaces, information, communication technologies, transportation, and various more services and facilities.

The certification program for green buildings, known as Leadership in Energy and Environmental Design (LEED), was created by the US Green Building Council. This program awards points to designing structures that are accessible to individuals with disabilities. These standards are widely used in the construction industry. In their efforts towards maintainable development, the United Nations (UN) and the Sustainable Development Goals (SDGs) place great importance on the moralities and presence of individuals having infirmities, highlighting the crucial role of universal accessibility. Numerous successful universal design projects, such as the retrofitting of public buildings in Kenya with ramps, serve as inspiring examples of how our collective efforts can make a difference (USGBC, n.d). According to Harpur (2012), the CRPD places great importance on universal accessibility and urges the elimination of obstacles that impede the complete contribution of disable individuals in society. The SDGs also recognize the privileges and inclusion of disabled individuals and highlight the significance of universal accessibility. Particularly, the Objective 10: Decreased Disparities and Objective 11: Environmental Cities and Districts have been introduced to specifically address this issue. Target 10.2 of Goal 10 emphasizes the need to encourage and advancement of the economic, the social and the political inclusion including all persons by the year 2030, irrespective of their race, origin,gender, age, disability, ethnicity, origin, race, creed, or financial or social status. Goal 10 aims to increase equality within and among nations. Goal 11 emphasises the significance of developing inclusive, secure, robust, and sustainable cities and communities that care for everyone's needs, including those of people with disabilities. As architects, urban planners, policymakers, and individuals involved in sustainable development and the building industry, you has a pivotal part in achieving these goals (Nations, 2015).

2.3.1 Research Already Conducted

As noted by Jrade & Valdez (2012), the aging global population is expected to bring about a rise in the prevalence of functional disabilities among individuals. The North American population has already experienced this phenomenon. To ensure an inclusive built environment that avoids segregation or stigmatization of any user, North Carolina State University (1997) has identified universal design to be similar to the creation of outcomes and conditions that can potentially be useful for all individuals, as to the fullest magnitude feasible, with no requiring modification or dedicated design. Accidents are a leading cause of death, ranking third after stroke, cancer, and heart attack. In Canada, home accidents account for 21% of these incidents, with young children and senior citizens being the most vulnerable (Lang-Runtz, 1983). The innovative approach presented by Jrade & Valdez (2012) involves the integration of Building Information Modeling (BIM) and a database management arrangement to establish universally applicable structures for both residential and commercial purposes. By implementing this methodology, it becomes possible to construct user-friendly models that facilitate the efficient and rapid development of sustainable building designs during the initial stages. The Government of Kenya has recognised the need for accessible housing for physically challenged individuals and older people. It has made it mandatory for all public buildings without ramps to be retrofitted with them (Arthur, 2016).

The field of architecture has become increasingly complex, requiring buildings to meet multiple criteria, such as fire safety, acoustics, and sustainability, among others. Before a building can be constructed, it must undergo a manual check against codes established by development authorities and government agencies, which can be prone to errors and result in increased costs and time consumption (Balaban, 2012). An automated compliance checking system is a viable alternative that can prevent costly mistakes and reduce the time required for manual checks (Eastman et al., 2009). Nevertheless, creating a distributed and integrated information management system for government regulations to ensure compliance is a challenging undertaking. (Kerrigan et al., 2004). To address this, Nawari (2012) proposed a method that effectively assesses the regulations and policies mandated by building codes and standards. This method uses a model-checking framework with rule-based systems to evaluate proposed designs. The outcomes of this assessment are categorized as either "pass," "fail," or "warning," and in instances where data is incomplete or unavailable, the system can generate an "unknown" result.

The built environment we inhabit is designed to meet various regulatory requirements to guarantee us security and welfare. Building designers undergo several assessments to check compliance in the design stage to guarantee that designs adhere to these regulations (Dimyadi & Amor, 2013). However, according to UNDP (2021), Pakistan's track record when it comes to safeguarding and empowering its disabled community is dismal. A total of 371,833 disabled people have been estimated in Pakistan (Statistics, 2021). However, many continue to go unnoticed and unheard, and legislative solutions have typically centred on charity, welfare payments, and rehabilitation (Wahla, 2019). Although there are design guidelines and standards in the Design Manual & Guidelines for Accessibility 2006 Government of Pakistan, 2006) to make buildings and facilities accessible to persons with disabilities, accessibility remains overlooked (Wahla, 2019). To address this issue, Hamieh (2017) proposed a technique for indoor path planning using a graph to highlight the shortest accessible path for people with disabilities. Han & Law (2002) developed an automated approach to analyse the toilet facility for disabled access.

Table 2.1: Identification of Research Gap

Sr.no.	**Sources**	**BIM**	**Specific Element from ADAAG/ Accessibility Code of Pakistan 2006**	**All elements**
1	(Han et al., 1998)	✗ IFC model	handicapped accessibility code compliance checking for doors	✗
2	(Han, Law, et al., 2002)	computer-based motion-planning techniques	wheelchair accessible route analysis	✗
3	(Hamieh et al., 2017)	✓	Indoor path planning (finding the shortest route)	✗

Sr.no.	Sources	BIM	Specific Element from ADAAG/ Accessibility Code of Pakistan 2006	All elements
4	(Nawari, 2012)	✓	✗ structural domain	✗
5	(Han, Kunz, et al., 2002)	✗ IFC model	usability analysis (w/c) for disabled access	✗
6	(Jrade & Valdez, 2012)	✓	Development of Universal Design Families	✗
7	Current Study	✓	Physical disability Visual Impairment	✓

2.3.2. Need for an Efficient System

Nawari (2012) states that professionals read, interpret, apply, and write building rules and regulations. The current method of comparing design and construction documents to a set of building codes that are constantly changing and becoming more complex is manual and prone to mistakes (Han et al., 1997). According to Acharya (2006), it can be difficult to determine whether a building design conforms with the code standards for individuals with disabilities, and design flaws are not always discovered prior to construction. (Alhosan; & Zhang, 2017). The inability to accurately evaluate designs for compliance can cause high, long-term costs. For instance, a large-scale housing project in south London constituted wheelchair ramps that were too steep and narrow, and the construction and design changes cost £800,000 (Ding et al., 2006). Because the human brain is less capable of reasoning and interpretation than computer systems, computerizing this process becomes extremely challenging for the AEC industry. This begs the question of what steps should be taken in order to successfully adopt automated code-checking (Nawari, 2012). By automating the procedure, irregularities caused by human verification may be eliminated, providing a standard framework for the designer and the permitting body to apply and check codes (Han et al., 1997). Ching (2018) further adds that the building official does not review accessibility compliance and has neither the authority nor the responsibility to enforce this federal law.

Jrade & Valdez (2012) contend that homes should be designed to be more accessible, comfortable, and safer for their inhabitants, particularly for seniors. They suggest that designers use tools to create 3D models that comply with Universal Design (UD) requirements for the built-in database. This will make it easier for architects and building contractors to apply UD principles to current and future structures and residences.

Adopting an automated BIM-based checking system may minimise spending on computations, printing, transportation, unnecessary meetings, and paying relevant staff to practically zero (Arendsen et al., 2014). An automated BIM-based checking system and an open platform for architects, engineers, and respective authorities may guarantee transparency in the design and approval process. It is a step forward for the AEC industry (Gu & London, 2010).

2.4 Building Information Modeling – BIM

BIM is a flexible and accomodating tool that integrates various project data, such as 3D models, cost and schedule information, environmental performance data, and facility management information, into a single source of truth (Al-Ashmori et al., 2020). According to Azhar (2008), a BIM model can be considered a “smart object” that contains comprehensive information about a building, encompassing its aesthetic and functional aspects and project lifecycle data. For instance, an air conditioning equipment's supplier, maintenance procedures, flow rates, clearance requirements, and the physical attributes of the unit would all be included in a BIM model. In order to achieve a seamless process, an integrated project delivery approach incorporating people, systems, business structures, and practices is made possible by BIM. This strategy seeks to improve productivity and cut waste at every level of the project life cycle. (Glick & Acree Guggemos, 2016). BIM allows architects, engineers, and builders to visualise a facility’s planning, design, construction, and operation in a virtual environment. This strategy can assist in locating any potential problems or conflicts that might develop throughout the construction process (Azhar et al., 2008). According to one study, stakeholders worldwide have adopted BIM to optimise their profitability and performance in multiple applications (Masood et al., 2014). These are as follows:

- 3D Coordination: This dimension creates a digital 3D model of the building, including its geometry, location, and orientation. Conflicts can be significantly reduced by checking the visual interface with integrated mechanical, electrical, and plumbing (MEP) systems.

- 4D Scheduling and Sequencing: This dimension adds a time element to the 3D model, adding the schedule and sequence of construction activities, ultimately tracking the project timeline.

- 5D Cost Dimension: This dimension integrates cost information with the 3D and 4D models, allowing for accurate cost estimation and management.

- 6D Sustainability Dimension: This dimension considers the environmental impact of the building or structure throughout its lifecycle, including factors such as energy consumption, carbon emissions, and waste management.

- 7D Facility Management Dimension This Operation and maintenance dimension involves integrating the building or structure's operational data into the BIM model, allowing for efficient maintenance, repair, and replacement activities.

- 8D Safety Dimension: This dimension involves integrating safety information into the BIM model, such as hazard identification and mitigation, emergency response planning, and compliance with safety regulations.

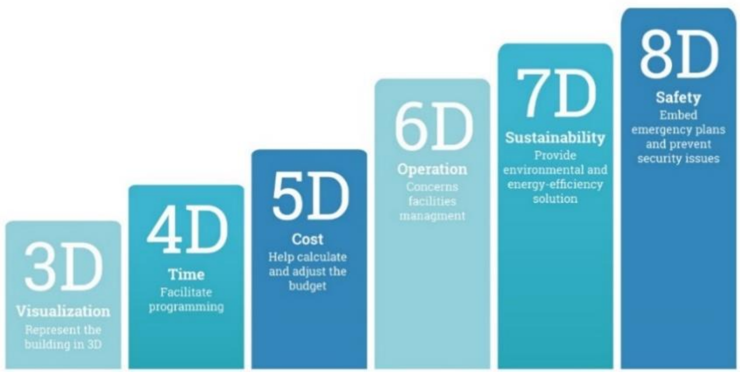

Figure 2.1: Dimensions of BIM

2.4.1 BIM as a Potential Solution

BIM can potentially play a significant role in creating more inclusive and accessible buildings. Using rule-based checking algorithms, visual representations of building designs, and managing accessibility features through BIM can significantly aid in ensuring compliance with building codes for universal accessible design. Over the past few decades, the use of BIM has grown in popularity throughout the AEC sector. Its advantages include enhanced collaboration, decreased errors, and more effective project delivery (Xie et al., 2022). By removing the laborious and..error-prone manual re-entry of information that characterises traditional paper-based workflows, BIM has significantly improved the exchange of information among stakeholders at every stage (Borrmann et al., 2018).

However, BIM has also been recognised as a tool for enhancing the accessibility and inclusivity of buildings, particularly for compliance with building codes for universal accessible design (Yu & Choi, 2023). He further adds that BIM can be utilised for automated code compliance checking of universal accessible design through the use of rule-based checking algorithms to check BIM models against relevant building codes and standards for accessibility, identifying and highlighting any areas of non-compliance for improving the design (Y. C. Lee et al., 2015). For example, one study by Sun & Kim (2022) developed a rule-based algorithm for checking the accessibility of doors in BIM models and found that the algorithm could identify a range of design errors, such as doors that were too narrow or lacked proper clearance space. Another example is aiding people with disability by finding the closest accessible route in the building (Han, Law, et al., 2002; Strug & Ślusarczyk, 2017). Another way in which BIM can aid in compliance with universal accessible design is by providing a visual representation of the building design, allowing designers and stakeholders better to understand the impact of design decisions on accessibility (Y. C. Lee et al., 2015). For instance, the researchers found that BIM enabled designers to visualise the accessibility features of the building better (Jrade & Valdez, 2012), such as clearance space in a universal design bathroom, leading to improved design outcomes.

2.5 Identification of Inefficiencies in Code Compliance

According to Acharya et al. (2006), Errors in design are sometimes overlooked until construction starts, and the results can be disastrous. Determining if a building design complies with the code requirements for individuals with disabilities is a challenging task. (Alhosan; & Zhang, 2017). Ching et al. (2018) further add that the building official does not review accessibility compliance and has neither the authority nor the responsibility to enforce this federal law; this makes the code compliance assessment inefficient.

Xue & Zhang, (2022) highlight that the manual process of reviewing designs is time-consuming and prone to errors and has become increasingly expensive to sustain. Failure to accurately evaluate designs for compliance can lead to substantial, long-term costs. Furthermore, studies by Alwisy et al. (2012), Greenwood et al. (2010), Soliman-Junior et al.(2021), manually verifying building designs for compliance with national and international codes is a complex process that involves redundant tasks that are prone to human error and incur high costs.

In various papers, several inefficiencies were observed and listed. Below listed in Table (2.2) are the collected inefficiencies in code compliance, where frequency denotes the number of papers mentioning the specific inefficiency.

Table 2.2: Issues/Inefficiencies in Code Compliance

Sr. No	**Inefficiencies**	**Description**	**Frequency**	**References**
1.	cost/ resource consuming	Manual design review takes a lot of time, is prone to mistakes, and is getting more and more expensive to maintain. Failure to accurately evaluate designs for compliance can lead to substantial, long-term costs.	40	(Jiang et al., 2022; Sydora & Stroulia, 2020; Wu, Akanbi, et al., 2022; Xue & Zhang, 2022)
2.	Time-consuming	Design review is conducted manually, checked against multiple building codes for adherence. This undertaking is intricate and requires a significant investment of time and resources.	37	(Doukari et al., 2022; Häußler et al., 2021; Jiang et al., 2022; Xue & Zhang, 2022)

Sr. No	Inefficiencies	Description	Frequency	References
3.	Misinterpretation (human error)	It can be challenging to eradicate mistakes and inconsistencies during the checking process because professionals make building rules and regulations.	34	(Aydın, 2021; Demir Altıntaş & Ilal, 2021; Jiang et al., 2022; Kim et al., 2020; Wu, Akanbi, et al., 2022; Xue & Zhang, 2022)
4.	Laborious	Building designs must be manually checked for compliance with national and international codes. It is a complicated process susceptible to human error, resulting in significant costs. The current manual practice increases the likelihood of participants overlooking crucial design problems or building code violations.	32	(H. Chen & Chan, 2021; Y. Chen et al., 2022; Jiang et al., 2022; Wu, Akanbi, et al., 2022; Wu, Zhang, et al., 2022; Xue & Zhang, 2022)

Sr. No	Inefficiencies	Description	Frequency	References
5.	Need for interoperability / heterogeneous information	The cooperation and sharing of information among various project stakeholders, utilising a universal model in architecture, engineering, and construction domains, establishes a data interoperability standard. This reduces bureaucracy and consolidates disparate documents into a single coherent building model.	28	(Y. Chen et al., 2022; Dimyadi & Amor, 2013; Y.-C. Lee et al., 2020; Lin & Guo, 2020; Nwadike et al., 2021; Wu, Akanbi, et al., 2022; Xue & Zhang, 2022)
6.	Poor communicatio n	Effective communication among the various personnel and teams involved in the process enables them to make decisions by considering the entire project rather	27	(Y. Chen et al., 2022; Demir Altıntaş & Ilal, 2021; Doukari et al., 2022; Jiang et al., 2022; Y.-C. Lee et al., 2020; Wu, Akanbi, et al., 2022)

Sr. No	Inefficiencies	Description	Frequency	References
		than just individual components, which can lead to unforeseen consequences.		
7.	visualisation	The capacity for stakeholders to obtain an accurate comprehension, and preferably a visual depiction, of the progress of a construction project at any given point.	23	(Y. Chen et al., 2022; Häußler et al., 2021; Soliman-Junior et al., 2021; Sydora & Stroulia, 2020; Wu, Akanbi, et al., 2022)
8.	Nonconformance to client needs	Nonconformance implies failure of a product or material to meet the customer's specifications or requirements. This can be due to a deflection in the process, design, documentation, or procedure, which may decrease product quality.	22	(Amor & Dimyadi, 2020; Aydın, 2021; Y. Chen et al., 2022; Doukari et al., 2022; Y.-C. Lee et al., 2020; Sydora & Stroulia, 2020; Wu, Akanbi, et al., 2022)

Sr. No	Inefficiencies	Description	Frequency	References
9.	Complexity	building codes can be complex and challenging to interpret. They are typically lengthy documents that contain a significant amount of technical information and legal jargon	21	(Alhosan; & Zhang, 2017; Y. Chen et al., 2022; Y.-C. Lee et al., 2020; Macit & Günayd, 2017; Nwadike et al., 2021; Soliman-Junior et al., 2021; Sydora & Stroulia, 2020)
10.	Inconsistency in assessment	The performance of buildings suffers when projects are improperly assessed for compliance and costly corrections are made.	20	(Aydın, 2021; H. Chen & Chan, 2021; Lin & Guo, 2020; Soliman-Junior et al., 2021; Wu, Akanbi, et al., 2022; Xue & Zhang, 2022)
11.	Inexperienced/ engineer/architect/code checker	The traditional approach to compliance checking is one of the significant current discrepancies in building regulation assessment. It has	18	(H. Chen & Chan, 2021; Lin & Guo, 2020; Nawari, 2020; Nwadike et al., 2021; Sydora & Stroulia, 2020;

Sr. No	Inefficiencies	Description	Frequency	References
		made it challenging to achieve optimal compliance, which is highly dependent on experts. This approach assumes that experienced professionals can accurately identify compliance issues through visual inspection and analysis of design documents		Wu, Akanbi, et al., 2022)
12.	Ambiguous	Ambiguity is an unclear statement, task or goal.	16	(Y. Chen et al., 2022; Doukari et al., 2022; Jiang et al., 2022; Y.-C. Lee et al., 2020; Nawari, 2020; Xue & Zhang, 2022)
13.	It affects the quality of work	Failure to comply with building codes can result in poor quality artistry, leading to costly and dangerous issues later.	16	(Y. Chen et al., 2022; Doukari et al., 2022; Häußler et al., 2021; Y.-C. Lee et al., 2020; Soliman-Junior et al., 2021)

Sr. No	Inefficiencies	Description	Frequency	References
		Building professionals should be aware of the relevant building codes and ensure that these codes complete all work.		
14.	Compliance is checked at the end of the project	The most effective way to ensure code compliance is not to check compliance at the end of the project. Throughout the entire construction process, it is crucial to make sure that the applicable building codes and regulations are followed. This can help to identify any potential issues early on and prevent costly and time-consuming changes at the end of the project.	15	(Aydın, 2021; Demir Altıntaş & Ilal, 2021; Häußler et al., 2021; Nawari, 2019, 2020; Soliman-Junior et al., 2021)

Sr. No	Inefficiencies	Description	Frequency	References
15.	Code awareness/ knowledge of applicable code	Knowledge and awareness of applicable building codes are essential. Architects, engineers, contractors, and other building professionals must be familiar with local, state, and national building codes that regulate everything from structural design and fire safety to plumbing and electrical systems. Failure to comply with building codes can result in costly fines, legal liabilities, and even the endangerment of lives.	13	(Aydın, 2021; Y. Chen et al., 2022; Demir Altıntaş & Ilal, 2021; Jiang et al., 2022; Y.-C. Lee et al., 2020)
16.	Repetition and revisions	Different municipalities often have varying definitions for the same services,	12	(Aydın, 2021; Y. Chen et al., 2022; Demir Altıntaş & Ilal, 2021; Jiang et

Sr. No	Inefficiencies	Description	Frequency	References
		leading to confusion during building code compliance checks. The drawings usually indicate the data required for compliance, but duplicating this information on both the specifications and the drawings increases the likelihood of document errors and inconsistencies.		al., 2022; Y.-C. Lee et al., 2020)
17.	misconduct/ mismanagement	Manual checking of building code compliance can lead to mismanagement for various reasons, including human error, lack of proper training, and inconsistent interpretation of codes. Code violations can go undetected without appropriate checks and balances,	11	(Asim et al., 2017; Aydın, 2021; Y. Chen et al., 2022; Doukari et al., 2022; Häußler et al., 2021; Wu, Akanbi, et al., 2022)

Sr. No	Inefficiencies	Description	Frequency	References
		leading to potential safety hazards and financial losses.		
18.	Access to code/ Data	Locating relevant codes can be time-consuming as they are not readily accessible, leading to delays in project completion and increased costs.	10	(Asim et al., 2017; Demir Altıntaş & Ilal, 2021; He et al., 2014; Nawari, 2020; Soliman-Junior et al., 2021; Xue & Zhang, 2022)
19.	Delay in approval/ long delay	The prolonged duration required for construction permit approvals by building authorities can have a negative financial impact on the project, with multiple revisions resulting in users having to undergo the same time-consuming process and waiting period.	10	(Aydın, 2021; Demir Altıntaş & Ilal, 2021; Kim et al., 2020; Nawari, 2019, 2020; Xue & Zhang, 2022)
20.	Lack of motivation	Organisations often hesitate to adopt new and more efficient	9	(Amor & Dimyadi, 2020; Y. Chen et al.,

Sr. No	Inefficiencies	Description	Frequency	References
		methods due to the learning process's perceived laborious and time-consuming nature.		2022; Demir Altıntaş & Ilal, 2021; Kim et al., 2020; Nwadike et al., 2021)
21.	Awareness of consequence	It is essential to comprehend the impact of non-compliance on both the building industry and the wider built environment	1	(Nwadike et al., 2021)
22.	Punishment of violators	Serial offenders are not appropriately punished because they are accused of negligence rather than breaking laws or rules, which is an inappropriate charge.	1	

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The main goal of this study is to develop an automated tool that minimises issues with universal accessibility code compliance. To achieve this, a research framework proposed by Nicholas Chileshea et al. (2019) was modified to suit the needs of this research, as shown in Figure 3.1. There are two phases to the study. Phase 1 of the project began with a thorough literature review to identify code compliance inefficiencies. After enlisting the inefficiencies, a close-ended questionnaire was distributed to AEC professionals to confirm the frequency and severity of the inefficiencies identified from the literature review. In Phase 2, a framework was created for automating code compliance using BIM with the help of the Revit Application Programming Interface (API). Professionals in the AEC industry will then review the final product.

The research methodology utilized to accomplish the study's goals is covered in this chapter.

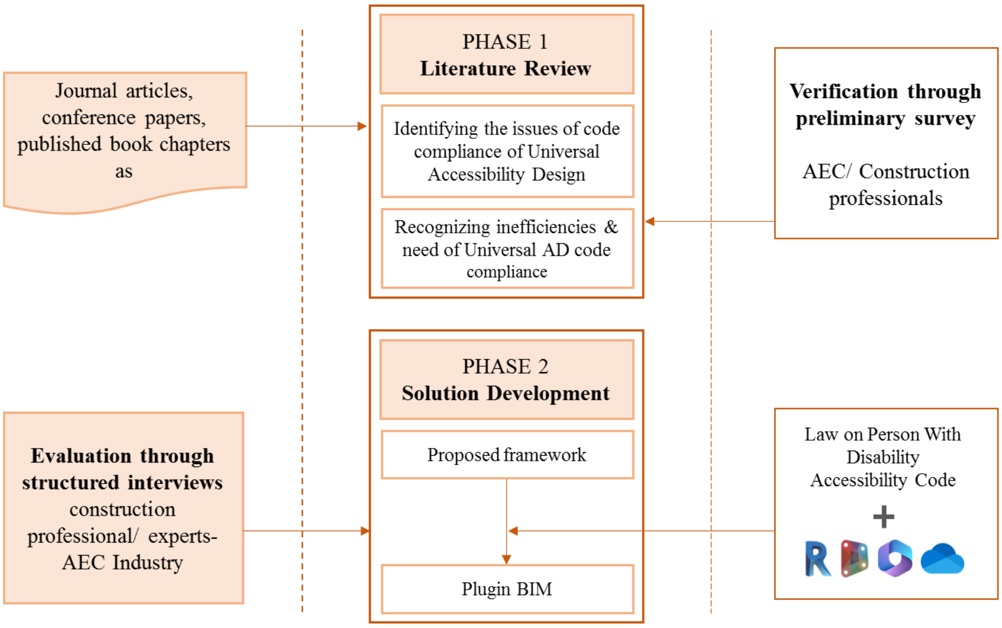

Figure 3.1: Research Methodology Framework

3.2 Objectives

- To analyse the inefficiencies in code compliance of Universal Accessibility Design

- To develop a framework for a BIM-based automated Accessibility Design Assessment.

- To realise the framework using a case study.

3.3 Research Design

The research methodology describes the strategy to accomplish the research objectives, which involves developing an automated tool to minimise inefficiencies in universal accessibility code compliance. A flowchart for research methodology has been created to facilitate the use of BIM and effective methods for code compliance. Figure 3.2 illustrates the steps to be followed throughout the research process, from start to finish.

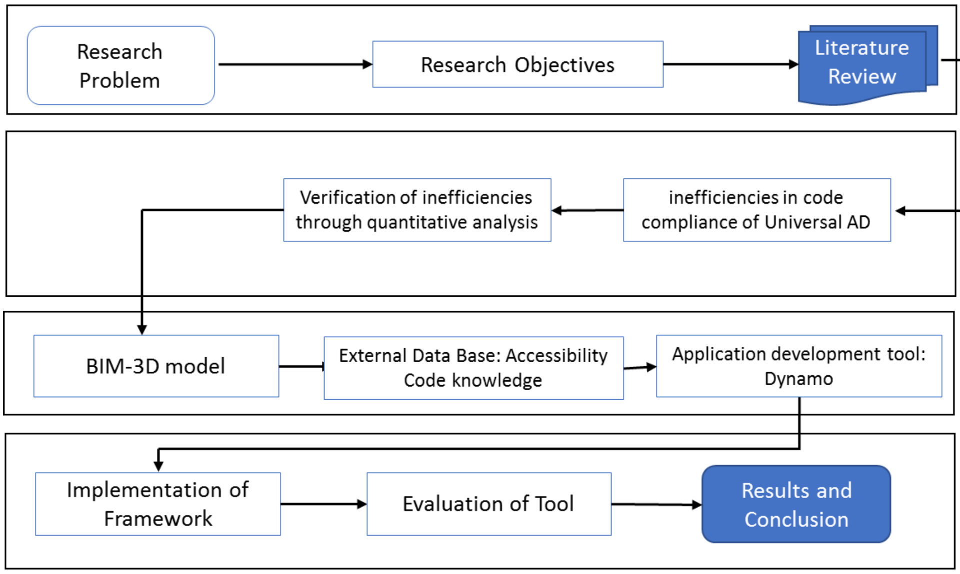

Figure 3.2: Research Methodology Flowchart

3.4 Identification of Inefficiencies in Code Assessment

According to Acharya et al. (2006), serious repercussions may result from design flaws that are not always discovered prior to the start of construction. Determining if a building design complies with the code requirements for individuals with disabilities is a challenging task (Alhosan; & Zhang, 2017). Ching et al. (2018) further add that the building official does not review accessibility compliance and has neither authority nor responsibility to enforce this federal law. Inadequate evaluation of designs for compliance can lead to significant and enduring expenses. As noted in section 2.3.2, a major housing project in south London incurred an expenditure of £800,000 for construction and design alterations because the wheelchair ramps were determined to be too steep and narrow (Ding et al., 2006).

Therefore, an extensive investigation of existing literature was carried out to extract many factors that influence the efficiency of code compliance. For searching the literature, sources like “ASCE”, “Science Direct”, “Google Scholar”, “Web of Science”, and “Emerald Insight” etc. were used. Keywords used in the search process include Building Code Compliance Checking, Universal Accessibility, Accessible design, People with Disability (PWD), Compliance Checking, Code Compliance Inefficiencies, etc. More than Forty (40) papers were analysed and scrutinised to obtain twenty-two (22) issues in the code compliance management process.

Table 3.1 enlists twenty-two (22) identified issues/inefficiencies in code compliance from previous research with their frequencies, i.e., occurrence in the number of papers. It can be seen that ‘cost/ resource consuming’ occurred 40 times in the literature, ‘time-consuming’ occurred 37 times, and ‘misinterpretation (human error)’ occurred 34 times in occurrence. From this, it can be ascertained that these factors play a significant role in code compliance in the construction industry.

A preliminary survey was conducted using an online questionnaire given to construction professionals with at least three years of experience in the construction industry to confirm the list of inefficiencies compiled for code compliance. A variety of professionals, including construction engineers, project managers, local government, licenced building officials, building contractors, architects, building and consulting engineers, and academics/researchers, were among the survey's participants. The respondents' profile is presented in Table 3.3, and Figure 3.2 and Table 3.2 provide information on the respondents' experience. Three sections made up the questionnaire used in this study: characteristics of the respondents' demographics, frequency of inefficiencies, and magnitude of severity of inefficiencies related to code compliance. Using the Relative Important Index (RII) method, participants rated the inefficiencies on a five-point Likert scale ranging from 1 (not at all) to 5 (extremely). The obtained data was then analysed and presented in Table 3.1.

$$\mathbf{RII} = \frac{\Sigma W}{A*N} \qquad \mathbf{(1)}$$

The RII (Relative Importance Index) ranges from 0 to 1 ($0 \leq RII \leq 1$). At the same time, W denotes the weight allocated by the participants to each factor, with the maximum weight A=5, and N represents the total number of participants.

Table 3.1: Issues/Inefficiencies in Code Compliance

Sr. No	**Inefficiencies**	**Frequency**	**Literature Score**	**Respondents Score**	**RII**
1.	cost/ resource consuming	40	0.952	3.500	0.700
2.	Time-consuming	37	0.881	3.618	0.724
3.	Misinterpretation (human error)	34	0.810	3.412	0.682
4.	Laborious	32	0.762	3.618	0.724
5.	Need for interoperability/ heterogeneous information	28	0.667	3.618	0.724

Sr. No	Inefficiencies	Frequency	Literature Score	Respondents Score	RII
6.	Poor communication	27	0.643	3.765	0.753
7.	visualisation	23	0.548	3.382	0.676
8.	Nonconformance to client needs	22	0.524	3.441	0.688
9.	Complexity	21	0.500	3.647	0.729
10.	Inconsistency in assessment	20	0.476	3.588	0.718
11.	Inexperienced/ engineer/architect/code checker	18	0.429	3.559	0.712
12.	Ambiguous	16	0.381	3.853	0.771
13.	Affect the quality of work	16	0.381	3.706	0.741
14.	Compliance is checked at the end of the project	15	0.357	3.618	0.724
15.	Code awareness/ knowledge of applicable code	13	0.310	3.941	0.788
16.	Repetition and revisions	12	0.286	3.676	0.735
17.	misconduct/ mismanagement	11	0.262	3.765	0.753
18.	Access to code/ Data	10	0.238	3.824	0.765
19.	Delay in approval/ long delay	10	0.238	3.971	0.794
20.	Lack of motivation	9	0.214	3.882	0.776

Sr. No	Inefficiencies	Frequency	Literature Score	Respondents Score	RII
21.	Awareness of consequence	1	0.024	3.794	0.759
22.	Punishment of violators	1	0.024	3.618	0.724

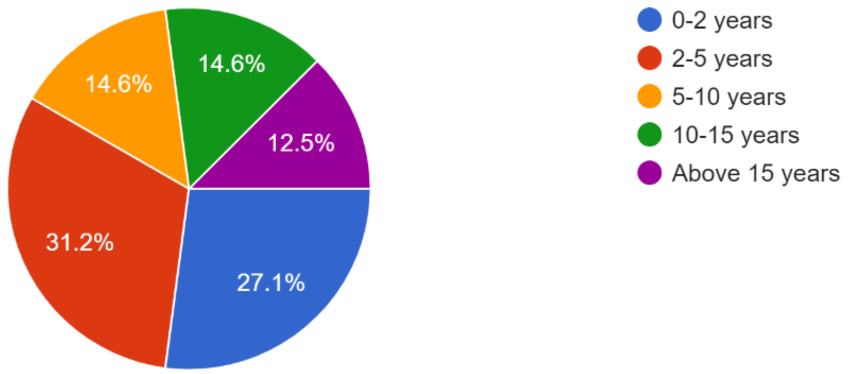

Figure 3.3: Experience of Respondents

Table 3.2: Experience of the Respondents

Experience in Years	No. of Respondents	Percentage %	Cumulative Percentage %
0-2	13	27.1	27.1
2-5	15	31.2	58.3
5-10	7	14.6	72.9
10-15	7	14.6	87.5
Above 15	6	12.5	100

Table 3.3: Profile of the Respondents

Group	No. of Respondents	Percentage %	Cumulative Percentage %
Architect	15	31	31
Project Manager	6	12.5	43.5
Project Engineer	2	4.2	47.7
Construction Manager	4	8.3	56
Site Engineer	1	2.1	58.1
Field Engineer	1	2.1	60.2
Civil Engineer	6	12.5	72.7
Construction Engineer	2	4.2	76.9
Planning and Contract Engineer	1	2.1	79
Project Coordinator	1	2.1	81.1
Project Manager, Project Engineer, Site and Civil Engineer.	1	2.1	83.2
Contract Specialist	1	2.1	85.3
Assistant BIM Manager	1	2.1	87.4
BIM Engineer	1	2.1	89.5
Academic Executive	1	2.1	91.6
Interior projects	1	2.1	93.7
Engineering Consultant	1	2.1	95.8
Architectural Engineer	1	2.1	97.9
Urban and Transport Planner	1	2.1	100

The factors extracted from the literature review were subjected to two main statements:

1. In the traditional (manual) evaluation method of code compliance for Universal accessibility (People with Disability), rate the frequency of the issues in manual code compliance.

2. In the traditional (manual) evaluation method of code compliance for Universal accessibility (People with Disability), rate the magnitude of the severity of the issues in manual code compliance.

3.5 Statistical Analysis

Respondents with experience ranging from 0-2 years were omitted to validate the collected data statistically. Various tests were performed on the collected data, details of which are discussed below.

3.5.1 Reliability Check on the Collected Results:

The reliability of Likert scale data is frequently evaluated using the Cronbach's Alpha method (Cronbach, 1951). The range of Cronbach's alpha is 0.0 to 1.0. when the data has a Cronbach's Alpha value of 0.7 or higher, it is considered reliable (Adamson & Prion, 2013; Cortina, 1993). According to Table 3.5, Cronbach's Alpha score for the questionnaire is 0.905. This value suggests that the data is very trustworthy.

Table 3.4: Cronbach’s Coefficient Alpha Processing Summary

Case Processing Summary			
		N	%
Cases	Valid	34	100.0
	Excluded[a]	0	0.0
	Total	34	100.0

Table 3.5: Cronbach's Coefficient Alpha Reliability Statistics

Reliability Statistics		
Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**N of Items**
0.905	0.907	22

3.5.2 Relative Variance in the Results:

The statistical method known as analysis of variance, or ANOVA, separates the observed variance data into distinct components for further analysis (Cleophas & Zwinderman, 2021). For data sets with three or more groups, one-way ANOVA determines the relationship between the dependent and independent variables. Statistical analyses were performed to check the level of difference through variance between groups of 30/70, 40/60, 50/50, 60/40 and 70/30. The p-value of ANOVA came out to be 0.95, showing a non-significant difference between the scores of the literature and respondents. Results are shown in Table 3.6 and Table 3.7.

Table 3.6: ANOVA Single Factor Summary

Groups	Count	Sum	Average	Variance
30/70	22	9.920736	0.450943	0.085136
40/60	22	9.622862	0.437403	0.084262
50/50	22	9.296399	0.422564	0.083385
60/40	22	8.937021	0.406228	0.082517
70/30	22	8.539487	0.388159	0.081676

Table 3.7: ANOVA Variation Summary

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.054226	4	0.013556	0.162556	0.956835	2.45821
Within Groups	8.756497	105	0.083395			
Total	8.810723	109				

3.5.3 Relative Importance Index RII

As shown in Table 3.8, a statistical technique called the RII is used to rank various factors (Azman et al., 2019; Genc, 2023). The RII for the 22-factor score was calculated using equation (1). The more significant the factor, the higher the value of RII.

$$\boldsymbol{RII = \frac{\sum W}{A * N}} \quad \textbf{(1)}$$

($0 \leq RII \leq 1$) whereas W is the weight assigned to each factor by the participants, the highest weight A=5 and the total number of participants is represented by N.

Table 3.8: RII Ranking of Inefficiencies

Inefficiencies	RII	60% weight	Literature Score	40% weight	Collective Score	Final Rank
cost/resource consuming	0.700	0.420	0.952	0.381	0.801	1

Inefficiencies	RII	60% weight	Literature Score	40% weight	Collective Score	Final Rank
Time-consuming	0.724	0.434	0.881	0.352	0.786	2
Laborious	0.724	0.434	0.762	0.305	0.739	3
Misinterpretation (human error)	0.682	0.409	0.810	0.324	0.733	4
Poor communication	0.753	0.452	0.643	0.257	0.709	5
Need for interoperability /heterogeneous information	0.724	0.434	0.667	0.267	0.701	6
Complexity	0.729	0.438	0.500	0.200	0.638	7
visualisation	0.676	0.406	0.548	0.219	0.625	8
Nonconformance to client needs	0.688	0.413	0.524	0.210	0.622	9
Inconsistency in assessment	0.718	0.431	0.476	0.190	0.621	10
Ambiguous	0.771	0.462	0.381	0.152	0.615	11
Inexperienced/ engineer/arch	0.712	0.427	0.429	0.171	0.598	12

Inefficiencies	RII	60% weight	Literature Score	40% weight	Collective Score	Final Rank
itect/code checker						
Affect the quality of work	0.741	0.445	0.381	0.152	0.597	13
Code awareness/ knowledge of applicable code	0.788	0.473	0.310	0.124	0.597	14
Compliance is checked at the end of the project	0.724	0.434	0.357	0.143	0.577	15
Delay in approval/ long delay	0.794	0.476	0.238	0.095	0.572	16
misconduct/ mismanagement	0.753	0.452	0.262	0.105	0.557	17
Repetition and revisions	0.735	0.441	0.286	0.114	0.555	18
Access to code/ Data	0.765	0.459	0.238	0.095	0.554	19
Lack of motivation	0.776	0.466	0.214	0.086	0.552	20
Awareness of consequence	0.759	0.455	0.024	0.010	0.465	21
Punishment of violators	0.724	0.434	0.024	0.010	0.444	22

3.6 Development of Prototype

A prototype is created in the second phase to address the problems found in the first phase. Initially, global standard accessibility codes were studied to take out the necessary information, standards, and guidelines for design. After studying the Accessibility Code standards, a prototype framework, as shown in Figures 3.4 and 3.5, was developed using attributes recognised by literature to minimise the above-identified inefficiencies.

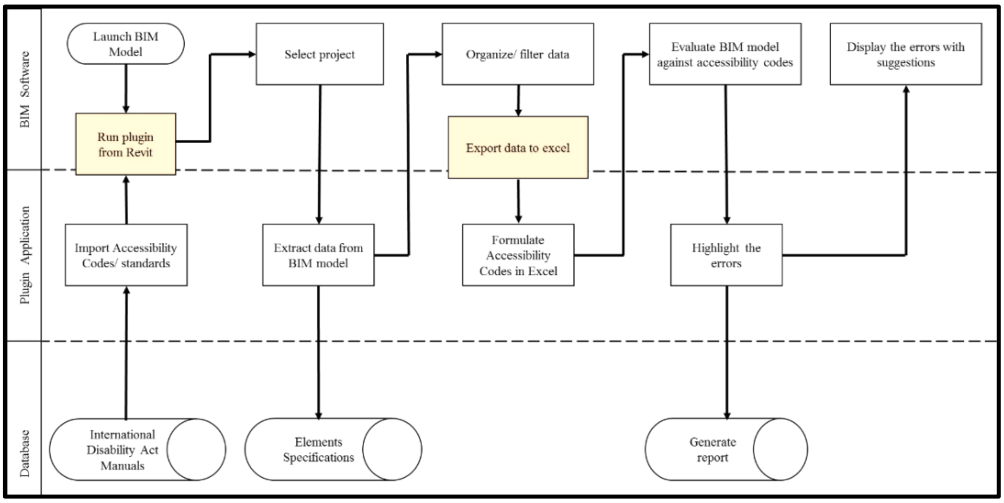

Figure 3.4: Research Framework

The concept is that Dynamo Player consists of Dynamo scripts which are run on a detailed BIM model. The scripts are created to run the assessment of Accessibility code. First, a detailed BIM model is created or uploaded; after clicking on the Plugin, the assessment result will be provided with highlighted errors. Hence, the BIM model is automatically updated with real-time project progress.

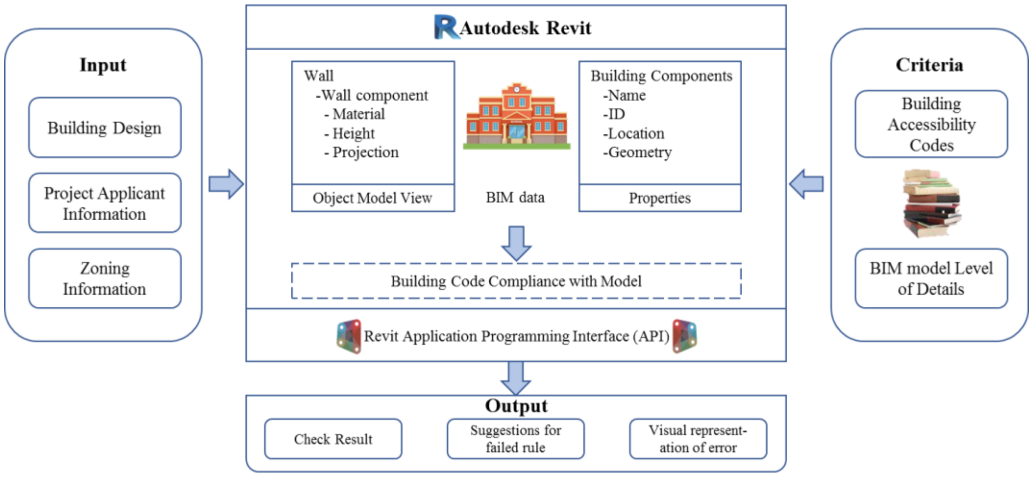

Figure 3.5: Proposed Prototype Framework

3.7 Validation of Prototype

A detailed BIM project has been uploaded to Revit. With the help of a Plugin, the Model is accessed against the respected Accessibility building codes.

CHAPTER 4:RESULTS AND ANALYSIS

4.1 Introduction

This chapter will explore using Dynamo in Revit to automate Universal Accessible Code Compliance, focusing on the American Disability Act (ADA) Accessibility Standards. We can enhance efficiency and accuracy by translating ADA guidelines into Dynamo scripts, running them in Revit, and exporting the results to Excel. This approach allows the AEC community to spend more time on the creative aspects of their work. The system integrates Revit for BIM, Dynamo for visual programming, and Excel for reporting results. Using Dynamo in Revit allows for the creation of custom scripts to automate tasks and manipulate data within the Revit environment. These scripts can range from simple tasks like renaming elements to complex operations like creating parametric designs and performing advanced analysis. The primary goal is to ensure that architectural designs comply with accessibility standards during the preliminary stage. Key components of the system include:

- Dynamo scripts for automated checks,
- Revit integration for running scripts, and
- Excel for summarising non-compliance issues.

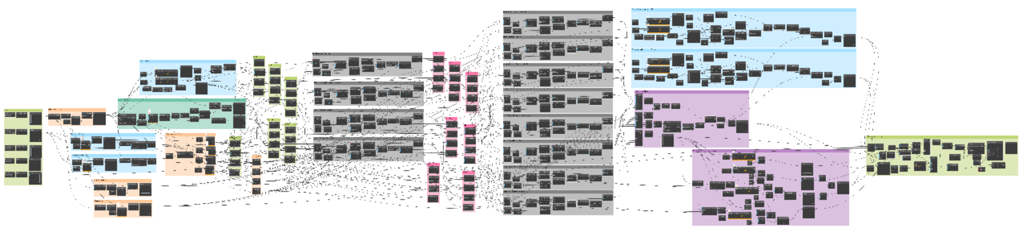

Figure 4.1: Dynamo Workflow

4.2 Overview of Dynamo Scripts

To illustrate the workflow of using Dynamo for my project, I present a structured overview of the key steps involved and their corresponding implementations. Table 4.1 provides a clear and concise summary of these steps, serving as a reference for readers to understand the Dynamo workflow in the context of my research.

Table 4.1: Overview of Dynamo Workflow Steps and Implementations

Sr.No	**Steps**	**Implementation**
1	Get Relevant Elements	By Categories
2	Filter as per Conditions	By Geometry, Parameters, Family Type
3	Get Checks Data	By Parameters, Formulas, Geometry
4	Code Compliance	By Mathematical Operations, Text Match, Geometry
5	Apply Checks	By AND logic
6	Code Compliance Display	By Listing, Excel Display

As shown in Table 4.1, the Dynamo workflow consists of six distinct steps, each with specific implementations tailored to project requirements. This structured approach ensures efficiency and accuracy in verifying architectural designs against ADA standards

4.2.1 Compliance Check Dynamo:

The flowchart below provides an overview of the Dynamo script designed to check door compliance in a Revit model according to ADA standards. The steps involved are:

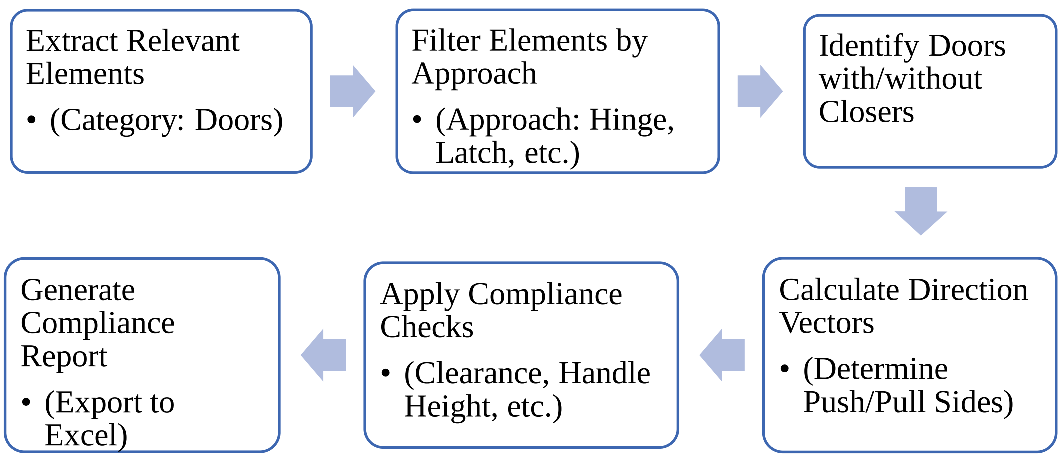

Figure 4.2: Dynamo Script Flowchart

4.3 Implementation of Automated ADA Compliance Checks Using Dynamo

The following entails how Dynamo is incorporated with Autodesk Revit for the compliance assessment. The Data used for structuring the code is from American Disability Act.

4.3.1 Door Compliance Checks Using Dynamo

The following table outlines the checks applied to doors in a Revit model to ensure ADA compliance. Each door type is examined based on various parameters such as family name, shared parameters, and geometric attributes.

Table 4.2: Door Compliance Checks Using Dynamo

Sr. #	Door	Approach	Closer	Checks		
	By Family Name	By Shared Parameter	By Geometry	Door	Appro-ach	Closer
1	Single	Front	Yes	Width, Handle Height, Threshold Height, Closer Height	Pull Side	Push with Closer
2			No			Push Side
3		Hinge	Yes		Pull Side	Push with Closer
4			No			Push Side
5		Latch	Yes		Pull Side	Push with Closer
6			No			Push Side
7		Recessed	Yes		Pull Side	Push with Closer
8			No			Push Side
9	Folding			Interference		
10	Pocket			Interference		

4.3.2 Parking Compliance Checks

The following table details the checks performed on parking spaces to ensure they meet ADA standards. These checks include dimensions and signage for different types of parking spaces.

Table 4.3: Parking Compliance Checks Using Dynamo

Sr.#	Parking (By Text)	Checks
1	Disabled Cars	Width, Height, Parking Sign, Parking Symbol Height, Aisle Width
2	Cars	Width, Height
3	Disabled Vans	Width, Height, Parking Sign, Parking Symbol Height, Aisle Width
4	Vans	Width, Height

4.3.3 **Toilet** Compliance **Checks**

The following table lists the checks for toilets to ensure ADA compliance. These checks are based on the type and parameters of the toilets.

Table 4.4: Toilet Compliance Checks Using Dynamo

Sr. #	Usage	Water Closet	Checks	
	By Parameter	By Type	Water Closet	Usage
1	General	Wall Mounted	Width, Depth, Door Width	Front and Side Toe Clearance (with exceptions in condition with
2		Floor Mounted	Width, Depth, Door Width	

Sr. #	Usage	Water Closet	Checks	
	By Parameter	By Type	Water Closet	Usage
				width and depths)
3	Children	Wall Mounted	Width, Depth, Door Width	Front and Side Toe Clearance (with exceptions in condition with width and depths)
4		Floor Mounted	Width, Depth, Door Width	

4.3.4 Stair Compliance Checks

The following table outlines the checks performed on stairs to ensure they meet ADA standards, focusing on riser and tread dimensions.

Table 4.5: Stairs Compliance Checks Using Dynamo

Sr. #	Stairs	Checks
	By Category	
1	Stairs	Minimum Riser, Maximum Riser, Minimum Tread

4.3.5 Railing Compliance Checks

The following table lists the checks for railings to ensure they comply with ADA standards. The checks include height and hand clearance based on usage.

Table 4.6: Railing Compliance Checks Using Dynamo

Sr. #	Railing	Usage	Checks
	By Category	By Parameter	Usage
1	Rails	General	Minimum Height, Maximum Height, Hand Clearance
2		Children	Maximum Height, Hand Clearance

4.3.6 Ramp Compliance Checks

The following table details the checks for ramps to ensure ADA compliance, including width, slope, rise, and safety features.

Table 4.7: Ramp Compliance Checks Using Dynamo

Sr. #	Ramps	Checks
	By Category	
1	Ramps	Clear Width, Max Slope, Rise, Landing, Handrails, Edge Protection

4.3.7 Protruding Objects Compliance Checks

To ensure ADA compliance, the following table lists the checks for protruding objects, such as lighting fixtures. The checks focus on the height and horizontal projection of protruding objects.

Table 4.8: Protruding Object Compliance Checks Using Dynamo

Sr. #	Lightning Fixtures	Hosting	Checks
	By Category	**By Geometry**	**Usage**
1	Protruding Objects	Wall	Minimum Height, Maximum Horizontal
2		Ceiling	Minimum Height

4.3.8 Post Compliance Checks

The following table outlines the checks for posts to ensure they meet ADA standards. The checks include height and protrusion distances for different types of posts.

Table 4.9: Clearance Compliance Checks Using Dynamo

Sr. #	Posts	Type	Checks
	By Category	**By No. of Columns**	**Usage**
1	Speciality Equipment	Free Standing Objects	Minimum Height, Maximum Height, Protrude Distance
2		Mounted Between Posts	Minimum Height, Maximum Height, Clear Distance

4.4 Overview

This is the overview of the dynamo script for the compliance check of 'Doors'. Firstly, all doors of a specific type, i.e. 'Single', as shown in *Table 4.10,* are extracted from the input model data. Consequently, the doors are filtered by their Approach parameter, i.e. ‘Hinge’, ‘Latch’, etc.

Table 4.10: Single Door Compliance Check

Sr. #	Door	Approach	Closer	Checks		
	By Family Name	By Shared Parameter	By Geometry	Door	Approach	Closer
1	Single	Front	Yes	Width, Handle Height, Threshold Height, Closer Height	Pull Side	Push with Closer
2			No			Push Side
3		Hinge	Yes		Pull Side	Push with Closer
4			No			Push Side
5		Latch	Yes		Pull Side	Push with Closer
6			No			Push Side
7		Recessed	Yes		Pull Side	Push with Closer
8			No			Push Side

For the checks, later on, it is essential to distinguish the doors with a closer and those without. This is done using another filter to sort each Approach type into two lists: one with Closer and one without.

Secondly, to distinguish between the Push and Pull sides of the door (essential for the checks), a direction vector corresponding to each door is calculated (See Implementation for details).

The checks are then divided into three categories: General Door, which applies to the whole door; checks concerning the Pull side of the door (which are used to a door irrespective of whether it contains a closer or not closer); and the checks concerning the Push side of the door which are different depending on whether the door has a closer or not.

The results of the checks can be used to find a final compliance check for each of the doors, and the information can be exported to an Excel file as the output.

4.4.1 Implementation Details:

The dynamo *Figure 4.3* represents the input to the script. We want all elements of specific Categories. Category 'Doors' contains a list of all the door objects in the model to be checked for compliance. The 'Generic Model' is essential because objects like Closer and Threshold belong to this category. Categories like 'Walls' and 'Furniture' are critical as they interact with the door and will be used in the subsequent compliance checks.

Figure 4.3: DATA Filtering in Dynamo Script

We will use the ‘Single’ door type to explain the implementation details. The first step is to sort all the ‘Single’ doors into a separate list from the list containing all of the elements of the category ‘Doors’ from the input.

This can be achieved by taking the *GetFamily* attribute of the door object. The 'Single' doors can be identified with the keyword 'Single' in their family name, for example 'Single-Flush' from the diagram above.

The family name must first be converted into a string to compare it with the string 'Single'. If a match is found, the output is True; otherwise, it is False. As a result, we have a list of type Boolean corresponding to the list of all category 'Doors' elements containing True if the door is of type 'Single'.

Once we have identified all the Single doors, we can fetch their attributes, such as their locations, etc.

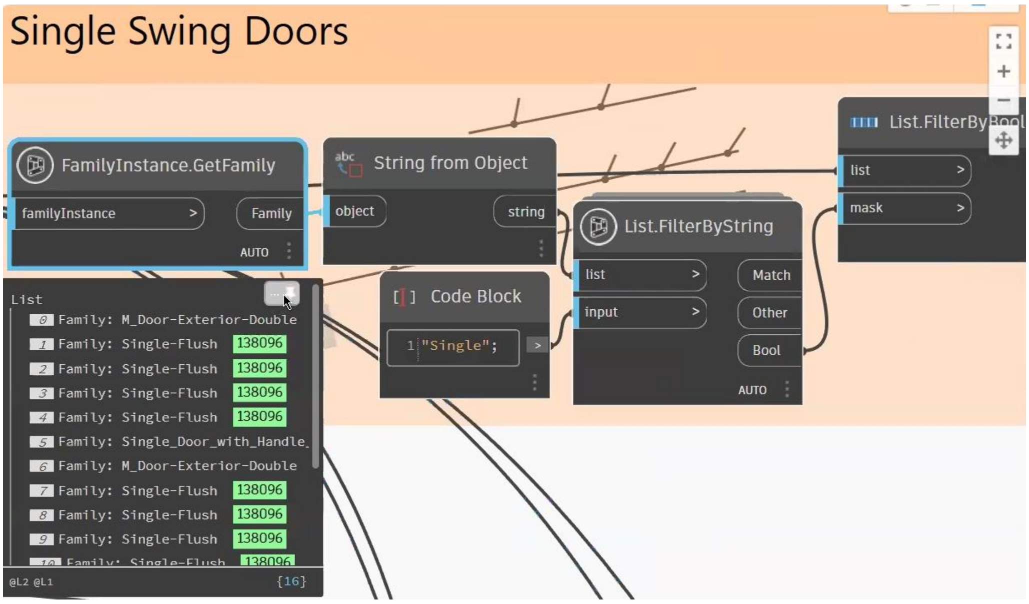

Figure 4.4: Door Category: Single Swing Doors

The second task is to determine the direction of the door, i.e., where the handle and hinges are located. This gives us information regarding the pull and push side of the door, which will be important later while applying the checks.

To determine the direction vector, we use a simple geometry trick. It is essential to realise that the location of the door is taken as the centre point of the wall where the door is embedded (See the yellow point in *Figure 4.5*. The door panel, when closed, has a slight offset compared to this central wall line of the door. Suppose we can find the middle location of the panel (see orange point *Figure 4.5*. In that case, we can calculate a direction vector from one point to the next by subtraction of the two positional vectors. The vector gives us the direction of the door opening.

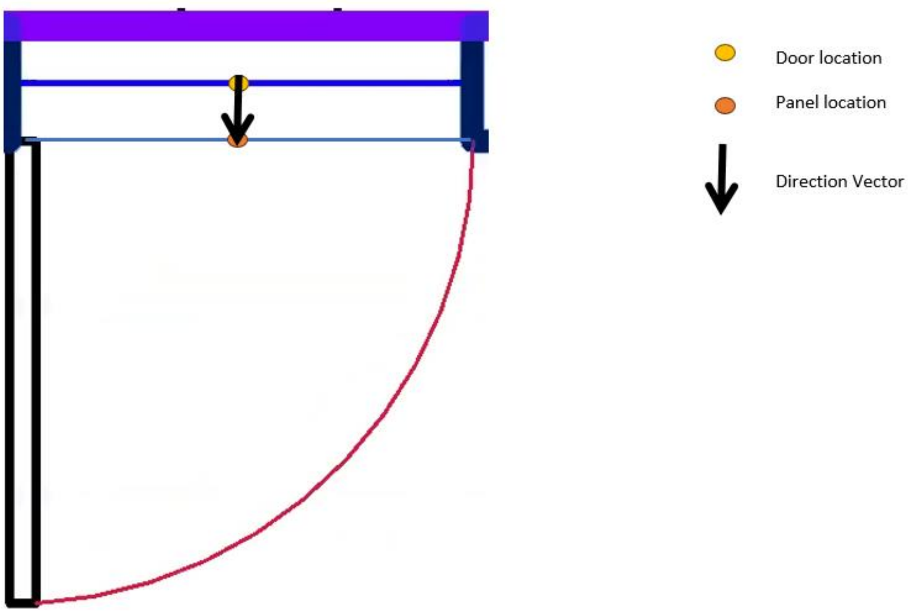

Figure 4.5: Door Direction Vector

The panel location is found by extracting the *revitGeometry* attribute corresponding to the subcategory 'Panel' of the door. We can then use the *GetLocation* method to find the *x* and *y* coordinates of the panel and take their centroid position to see the orange point above.

To find the location of the door, we use the attribute Host of the door element and the method *GetLocation* to find the *x and y* coordinates of the wall hosting the door and take the centroid position as before.

In this step, we also perform two additional tasks: extracting the handle position of the door element by using the attribute *HandOrientation.* Secondly, we find a *door vector* for each of the doors. The door vector starts from the door location (see yellow point in *Figure 4.5*) and terminates along the z-direction at the attribute 'height' of the door. This door vector is calculated for each door and gives us the door position in 2D. It will be used later on to develop the filter for doors with closers.

The next step in the workflow is to filter the doors further using their *Approach* attribute, i.e. filter the list of *Single* doors into four different lists, each corresponding to one of the Approach types (*Front*, *Hinge*, *Latch* and *Recessed*). We employ a similar procedure to when we wanted to sort all the doors of type 'Single' and use string matching to identify which elements from the list correspond to the string Front", for example.

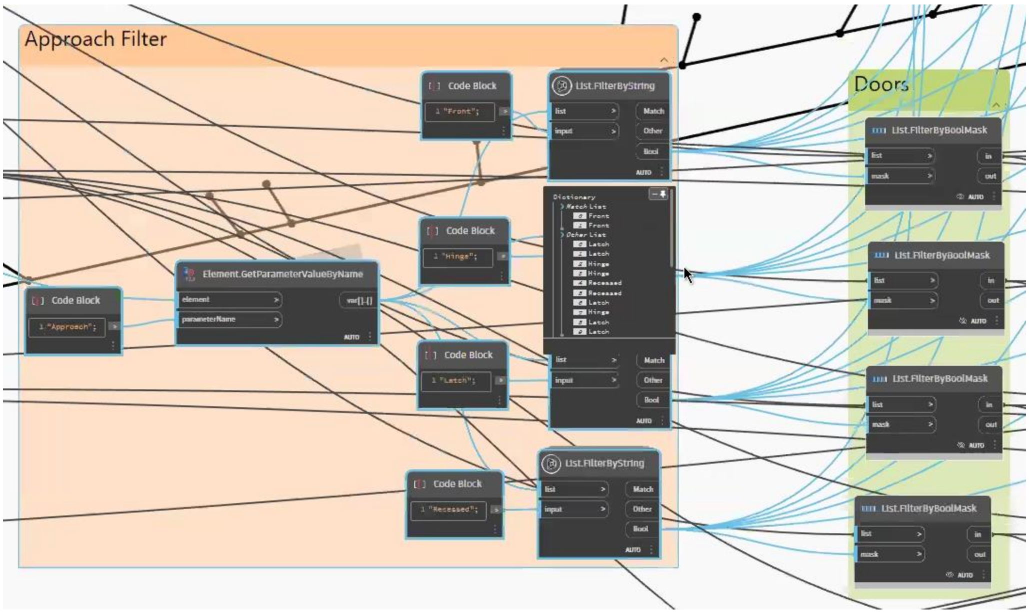

Figure 4.6: Approach Filter

The next step is to create a Closer filter which sorts all the door closers objects (which belong to the category Generic Model) into a separate list. However, the problem is that even though we independently know the locations of all the doors (from category *Doors*) and locations of all the closer objects (from category *Generic Models*), we have yet to learn which doors have closers and which do not.

First, we used a similar procedure when we wanted to sort all the doors of type ‘Single’. All the door closer elements contain the word ‘Closer’ in their name, and we can again use string matching to find out the element locations (list indices) of the door closer from the raw list containing all the elements from the category *Generic Models*.

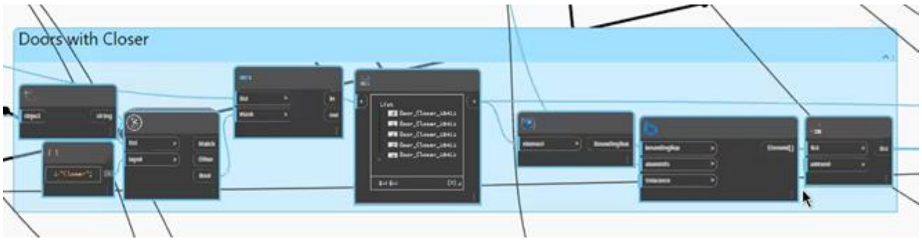

Figure 4.7: Doors With Closer

We then use the method of BoundingBox to draw a virtual bounding box around the (physical) location of the closer. Now is where we need the door vectors calculated in Step 2. The idea is that if we perform an intersection between the bounding box location of one closer object and each of the door vectors and get a hit (that is, intersection with a particular door vector yields a non-null value), then we know that the specific door in question has a closer attached. We then make two output lists: one containing the doors with closers and the other without.

Now that our Closer Filter is ready, we apply it in cascade after the Approach filter. The result is that we have eight lists in total. For each list sorted by Approach, we split it into two lists, for example, doors with Hinges with closer and doors with Hinges without closer and the same for the other 3 Approach types.

A side note has to be mentioned here that after all the filtering, the newly sorted lists have lost all correspondence with the Direction Vector, Width, Door Vector, and Door locations lists whose elements corresponded to the original, raw list containing all door elements from the Doors *Category*. To circumvent this, we apply the same steps (filtering) to these lists as we did to the original Doors List. We have corresponding Direction Vector, Width, Door Vector, and Door locations lists for each of the eight filtered Doors lists. A similar approach finds all the Threshold objects within the list.

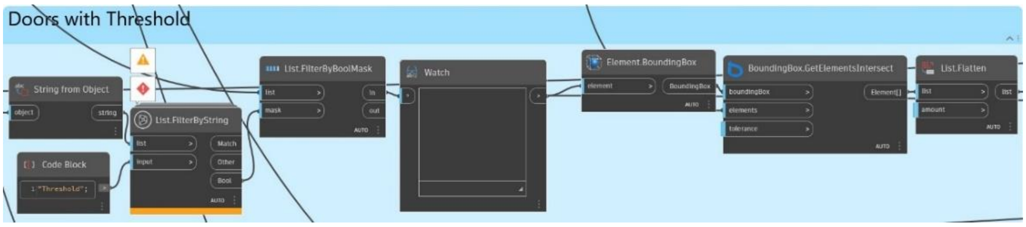

Figure 4.8: Doors With Threshold

Now, we come to the final step: applying the checks. First, let us deal with the checks for the pull side because these checks do not depend on whether the door is closer. Let us consider the Latch Approach. It takes five parameters as inputs: For a particular door (sorted into the Latch list), it takes its door vector (l), door point (p), width (w), direction vector (o) and height (h).

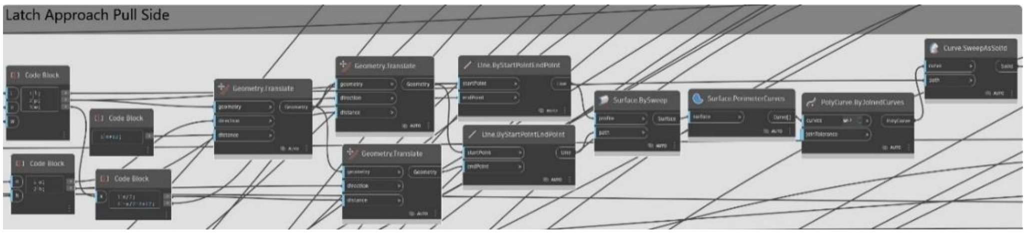

Figure 4.9: Approach- Latch Approach Pull Side

The idea is to draw a shape (3-D volume) around the door, representing the constraints to which the specific check applies. For example, here we see a clearance of 4 feet (multiplied by 12 because we want the unit in inches) in the direction of the door's opening (i.e. pulling of the door) as required by the check.

Similarly, clearance is needed in the x-direction (See diagram below). Once the 2D shape is drawn, a 3D volume can be swept from the area in the z-direction (direction of the door height). It should be noted that the volume swept only represents *half* of the door space (the Pull side). The Push side volume has to be calculated as this differs depending on whether the door has a closer or not (of course, if the door has a closer, it would require a larger clearance than the door, which does not have a closer). Once we have both sides of the volume of a door drawn, we can form a union over them.

Now, the idea is that we can take an intersection of this volume and the (physical) locations of the objects close to the doors, such as elements from the category *Furniture.* If we see an intersection, we know the Interference check for that particular door (whose volume we intersect) has failed.

It should be noted that the code for the other 3 *Approach* types is also very similar. The only difference is the clearance in the *x*, *y* and *z* directions as dictated by the compliance checks.

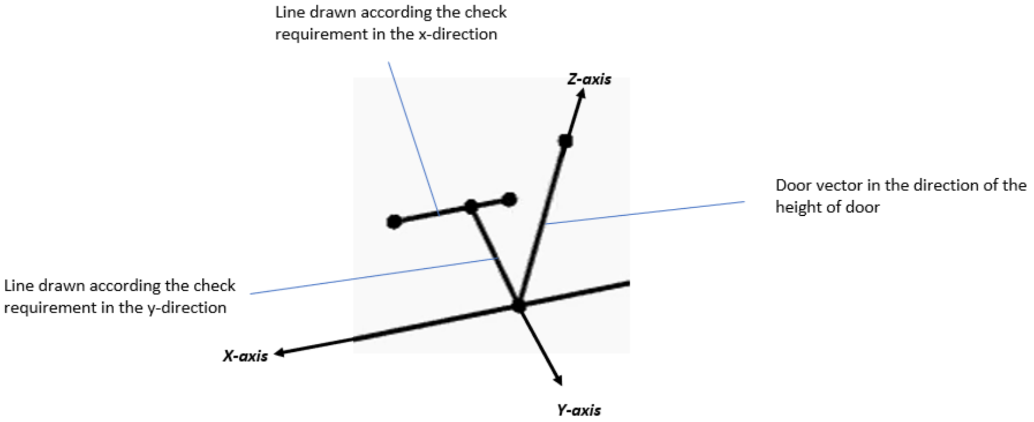

Figure 4.10: Detail of Door Vector

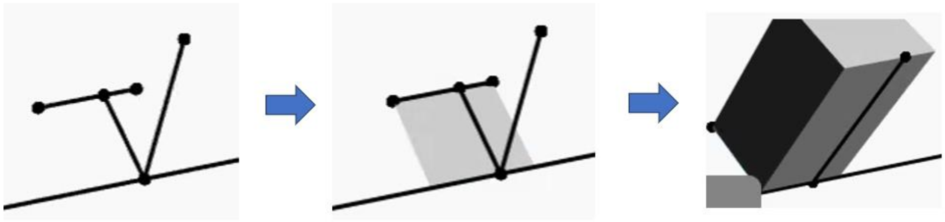

Figure 4.11: Envisioning 3D Volume Space of Door

Other general door checks include *Width Check*, *Handle Height Check*, *Closer Height Check, and Threshold Height Check.* These are straightforward, as the relevant data can be extracted from the attributes of the objects.

Ultimately, the Code Compliance for a specific door is verified by applying the AND operator to all the results of the checks (Boolean values; True if the check passes, False if it fails) for the door in question. This means the Code Compliance will only return true if every check for the door is passed. It is important to note that this condition assumes the door has a non-null value, as a door without a closer will not need to be checked for the Closer Height Check.

The process is also implemented for door types other than *single, such as folding doors and pocket doors, but* the implementation is the same.

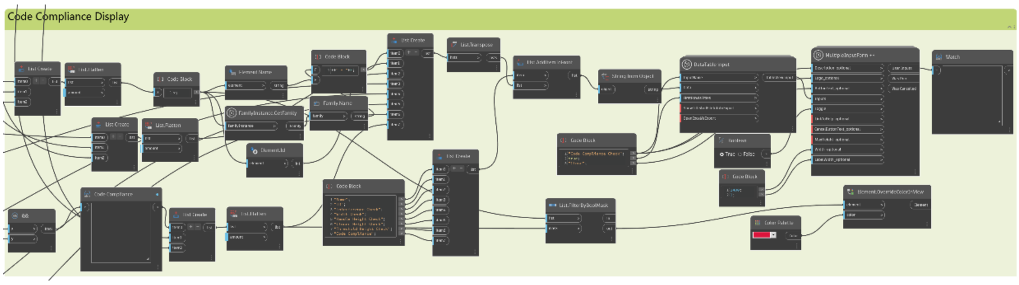

Figure 4.12: Code Compliance Display

4.5 Steps Taken for ADA Compliance Checks Using Dynamo

The first stage of automating the accessibility assessment entails uploading or creating the building model using BIM software like Revit. This ensures that all relevant architectural details are included for an accurate evaluation. Once uploaded, the model is checked for compliance with ADA standards.

Before the detailed assessment, it is essential to visualise the model in its original state. This establishes the baseline condition, enabling us to pinpoint areas for evaluation. Following the accessibility assessment, the model is re-evaluated to showcase modifications and improvements, highlighting identified issues and their resolutions. The final step involves exporting the assessment results to an Excel sheet, providing a comprehensive overview of identified problems, locations, and the actions taken for a clear and organised review.

4.5.1 Step 1: Model Upload/Development

- Upload the building model to the BIM software (e.g., Revit).
- Ensure all relevant architectural details are included for accurate assessment.

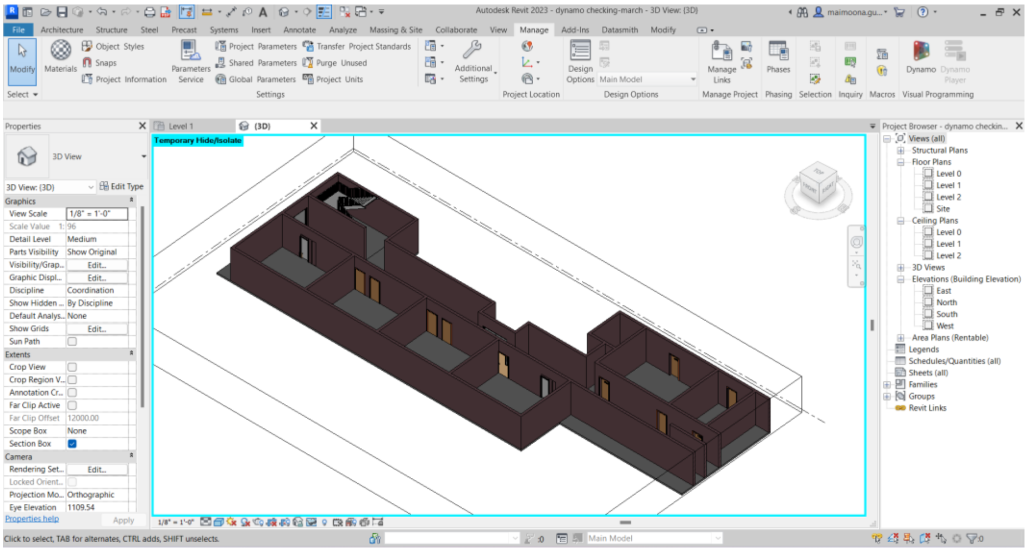

Figure 4.13: Input - Uploading/Development of Model

4.5.2 Step 2: Model Screening

- Initiate the screening process within the BIM software using Plugins created in Revit.
- The software scans the model for compliance with ADA standards.

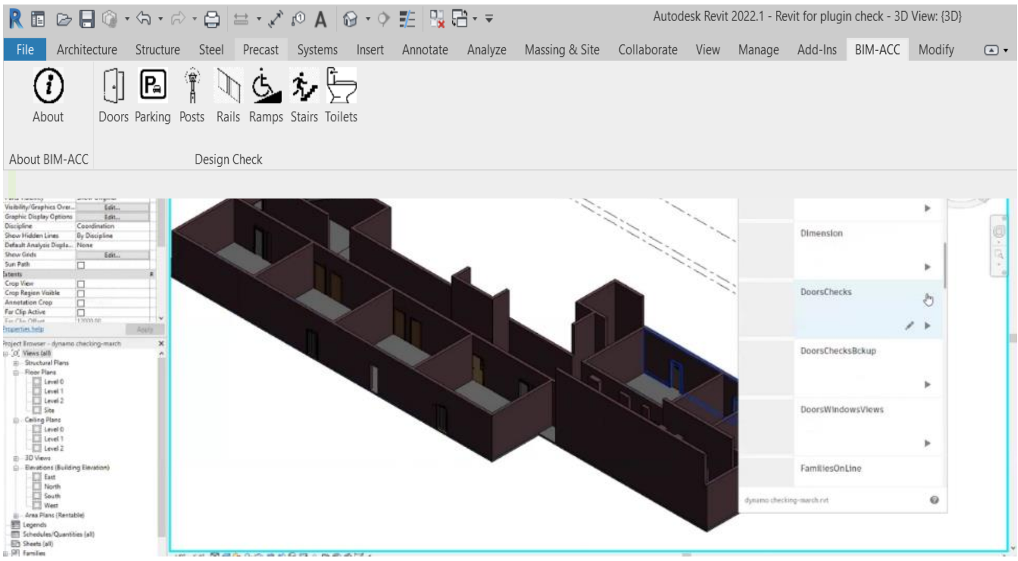

Figure 4.14: Model Screening

4.5.3 Step 3: Visual Representation - After Assessment

- Show the model after the accessibility assessment has been run.
- Highlight and indicate the areas where issues were detected and addressed.

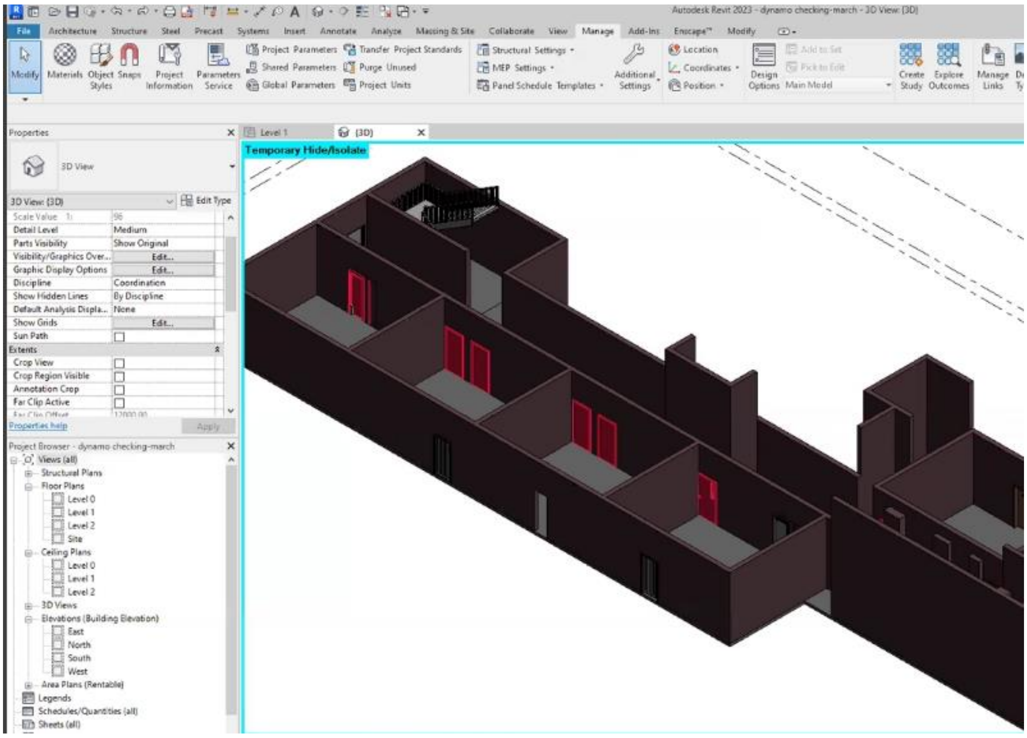

Figure 4.15: After Assessment- Visual Representation

4.5.4 Step 4: Export and Review Results

- Export the assessment results to an Excel sheet.
- Review the report, focusing on the errors detected against ADA standards.
- Highlight the critical issues in the model space for further action.

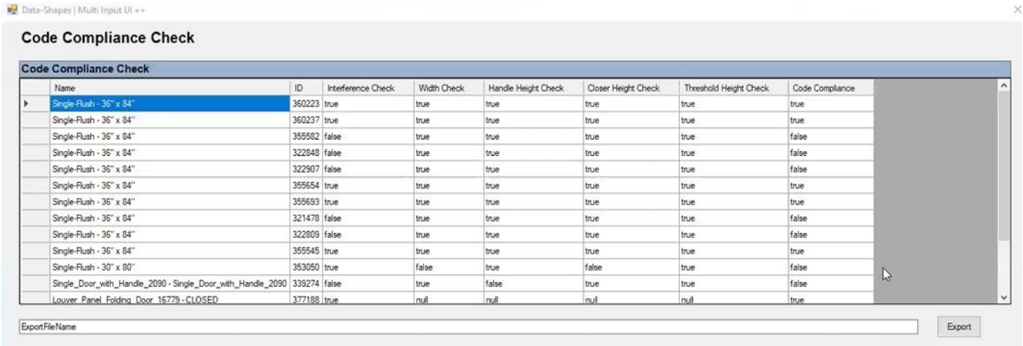

Figure 4.16: Output - Excel Sheet Display Report (a)

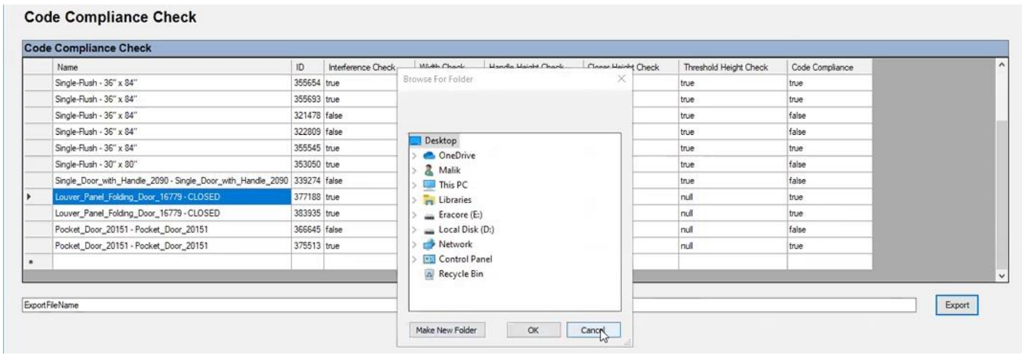

Figure 4.17: Output - Excel Sheet Display Report (b)

4.6 Validating the Code Compliance Assessment Tool

One-to-one semi-structure interviews with 22 practitioners with > 07 years of experience. First, Evaluation of the BIM- Automated Code Compliance (BIM-ACC) plugin in accordance the parameters. Experts agreed that the developed plugin BIM-ACC is an effective tool to deal with the code compliance assessment. Then, rated the Effectiveness of BIM-ACC in resolving the inefficiencies identified during the first phase. All factors having RII > 0.6 shows the issue resolving capability of BIM-ACC.

Table 4.51: Evaluation Table (a)

Evaluation Type	Evaluation Parameters	cumulative	Average	RII
Physical	Usability of BIM-ACC interface	113	4.52	0.904
Affective	BIM-ACC need in the construction industry	117	4.68	0.936
	BIM-ACC effectiveness to improve assessment process	119	4.76	0.952
	BIM-ACC to improve the performance of the project	119	4.76	0.952
Cognitive	BIM-ACC implementation	114	4.56	0.912
	Overall experience of using BIM-ACC	119	4.76	0.952

Table 4.62: Evaluation Table (b)

No.	Inefficiencies in Code Compliance Assessment	Evaluation scores for BIM-ACC
		RII
1.	Cost/ Resource consuming	0.96
2.	Time consuming	0.888
3.	Misinterpretation	0.928
4.	Laborious	0.952
5.	Poor collaboration between stakeholders	0.88
6.	Poor communication	0.904
7.	Non-conformance to clients needs	0.92
8.	Inconsistency in assessment	0.952
9.	Ambiguous statements	0.936
10.	Affects quality of work	0.952
11.	Compliance is checked at the end of project	0.928

All factors having RII > 0.6 shows the issue resolving capability of BIM-ACC.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Traditionally the evaluation of the building designs against code compliance is conducted manually. This manual assessment is error prone, time consuming, and inefficient. This research emphasised the importance of the Building Information Modelling (BIM) and need for substituting traditional method to the programmed code compliance inspection system.

The proposed BIM-based structure is achieved by translating the ADA code to Dynamo script. Dynamo is a optical programming instrument that can be run in Autodesk Revit. This combination results in automating the code compliance assessment against American Disability Act (ADA) Accessibility Standards. This automation promotes transparency and enhances efficiency of the design review process. Errors could be identified in an early-preliminary stage, offering room for rectification.

Key findings from the study include:

1. **Efficiency and Accurac**y: Translating the ADA code to Dynamo script streamlined the accessibility assessment process. Consistent results enhanced both efficiency and accuracy
2. **Scalability and Flexibility**: The Dynamo script can be assessed against various files that need to be assessed for accessibility

3. **Transparency and Collaboration**: The automated code compliance checking system promotes transparency in the design review and approval process.

To conclude, the implementation of a BIM-based automated code compliance audit for universal accessibility design requirements optimizes accessibility and minimizes the need for future renovations, emphasizing the necessity of automation and digitalization in enhancing inclusivity and efficiency in architectural design and construction processes. Automating the universal accessible design assessment can potentially enhance the overall productivity and value of the evaluation process.

5.2 Recommendations

Following recommendations can be made to further advance the integration of BIM in accessibility assessments and promote Universal Design principles:

1. **Adoption of BIM-Based Systems**: There is a hesitation in adopting and adapting to new technology, to this date traditional methods are used. It is recommended to step out of the comfort zone and progress by adopting BIM-based systems. Sufficient training should be provided for a smooth transition.
2. **Standardization of Compliance Checks**: This research focuses on Americans with Disabilities Act (ADA) standards for Accessible Design. Specific elements from Chapters 3-6 were incorporated in the Dynamo script code rather than entirety of the content. The development of standardized Dynamo scripts for various accessibility codes (ADA,

International Building Code (IBC), UK Building Regulations, etc.) should be pursued to automate code compliance assessments across different regions.

By adopting these recommendations, the AEC industry will take a significant step towards inclusivity and efficient design practices, ultimately ensuring the built environment to be accessible to all individuals.

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APPENDIX A.

MS Thesis Survey: Evaluating The Inefficiencies in Manual Code Compliance For Universal Accessibility

Introduction:

This Dear Respondent,

This survey is part of my MS thesis titled "A BIM-Based Framework for Code Compliance Audit of Universal Accessibility Design Requirements." The goal is to evaluate the inefficiencies in traditional manual evaluation methods for Universal Accessibility (People With Disabilities) compliance and explore potential BIM-based solutions.

Survey Instructions:

Please rate the magnitude of severity for each of the following inefficiencies in manual code compliance using the Likert scale:

- **1:** Not at all
- **2:** Slightly
- **3:** Moderately
- **4:** Very
- **5:** Extremely

Your feedback is crucial in understanding these challenges and identifying opportunities for improvement.

Privacy Note: All personal data will be kept confidential and used solely for research purposes.

Contact Information:

- **Researcher:** Maimoona Gul
- **Post Graduate Student,**

  Department of Construction Engineering and Management,

  School of Civil and Environmental Engineering (SCEE),

  NUST Institute of Civil Engineering (NICE),

  National University of Sciences and Technology (NUST), Islamabad, Pakistan.

- **Email:** maimoona.cem20nit@student.nust.edu.pk

  maimoona.gul18@gmail.com

Participant Information:

- **Name:** [Text Box for Response]
- **City, Country:** [Text Box for Response]
- **Experience (years) in Construction Industry:**
  - ○ 0-2 years
  - ○ 2-5 years
  - ○ 5-10 years
  - ○ 10-15 years
  - ○ Above 15 years

- **Experience in Construction Industry as:**
  - ○ Consultant
  - ○ Contractor
  - ○ Client
  - ○ Other: [Text Box]

- **Designation:**
  - ○ Architect
  - ○ Project Manager
  - ○ Project Director
  - ○ Project Engineer
  - ○ Construction Manager
  - ○ Site Engineer
  - ○ Field Engineer
  - ○ Civil Engineer
  - ○ Construction Engineer
  - ○ Other: [Text Box]

Survey Question (1):

In the traditional (manual) evaluation method of code compliance for Universal accessibility (People With Disability), I have listed below the following inefficiencies.

According to your experience and scholarly opinion, please rate the frequency of the following factors in terms of Likert scale 1-5:

1. Always
2. Often
3. Sometimes
4. Rarely
5. Never

<u>You are required to rate the inefficiencies in traditional (manual) evaluation according to your experience and opinion</u>

Sr No.	**Inefficiency**	**Always**	**Often**	**Sometimes**	**Rarely**	**Never**
1	Cost/ Resource consuming	○	○	○	○	○
2	Time consuming	○	○	○	○	○
3	Misinterpretation	○	○	○	○	○
4	Laborious	○	○	○	○	○
5	Poor collaboration between stakeholders	○	○	○	○	○
6	Poor communication	○	○	○	○	○

Sr No.	**Inefficiency**	**Always**	**Often**	**Sometimes**	**Rarely**	**Never**
7	Visualization only for aesthetic purpose	○	○	○	○	○
8	Non-conformance to clients needs	○	○	○	○	○
9	Building codes are complex documents	○	○	○	○	○
10	Inconsistency in assessment	○	○	○	○	○
11	Inexperienced engineer/ architect/ code checker	○	○	○	○	○
12	Ambiguous statements	○	○	○	○	○
13	Affects quality of work	○	○	○	○	○
14	Compliance is checked at the end of project	○	○	○	○	○
15	Lack of knowledge of applicable codes	○	○	○	○	○
16	Repetition and revision	○	○	○	○	○
17	Mismanagement	○	○	○	○	○
18	Inadequate access to data	○	○	○	○	○
19	Delay in approval	○	○	○	○	○
20	Lack of motivation	○	○	○	○	○

Sr No.	**Inefficiency**	**Always**	**Often**	**Sometimes**	**Rarely**	**Never**
21	Lack of Awareness of consequences	◯	◯	◯	◯	◯
22	No punishment to violators	◯	◯	◯	◯	◯

Survey Questions (2):

In the traditional (manual) evaluation method of code compliance for Universal accessibility (People With Disability), I have listed below the following inefficiencies.

According to your experience and scholarly opinion, please rate the magnitude of severity of the following issues in manual code compliance in terms of Likert scale 1-5:

1. **Extremely**
2. **Very**
3. **Moderately**
4. **Slightly**
5. **Not at all**

Measuring the severity of the issues, shortlisted through the literature review:

Sr No.	**Inefficiency**	**1 (Extremely)**	**2 (Very)**	**3 (Moderately)**	**4 (Slightly)**	**5 (Not at all)**
1	Cost/ Resource Consuming	○	○	○	○	○
2	Time Consuming	○	○	○	○	○
3	Misinterpreta tion	○	○	○	○	○
4	Laborious	○	○	○	○	○
5	Poor Collaboratio	○	○	○	○	○

Sr No.	**Inefficiency**	**1 (Extremely)**	**2 (Very)**	**3 (Moderately)**	**4 (Slightly)**	**5 (Not at all)**
	n Between Stakeholders					
6	Poor Communication	○	○	○	○	○
7	Visualization Only for Aesthetic Purpose	○	○	○	○	○
8	Non-conformance to Clients' Needs	○	○	○	○	○
9	Building Codes are Complex Documents	○	○	○	○	○
10	Inconsistency in Assessment	○	○	○	○	○
11	Inexperienced Engineer/Architect/Code Checker	○	○	○	○	○
12	Ambiguous Statements	○	○	○	○	○
13	Affects Quality of Work	○	○	○	○	○
14	Compliance Checked at End of Project	○	○	○	○	○
15	Lack of Knowledge of	○	○	○	○	○

Sr No.	**Inefficiency**	**1 (Extremely)**	**2 (Very)**	**3 (Moderately)**	**4 (Slightly)**	**5 (Not at all)**
	Applicable Codes					
16	Repetition and Revision	○	○	○	○	○
17	Mismanage ment	○	○	○	○	○
18	Inadequate Access to Data	○	○	○	○	○
19	Delay in Approval	○	○	○	○	○
20	Lack of Motivation	○	○	○	○	○
21	Lack of Awareness of Consequence s	○	○	○	○	○
22	No Punishment to Violators	○	○	○	○	○