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Research Article/ Review Article/ Perspective Article (Remove where relevant)

Integrating Accessibility Assessment into Architectural Design: A Building Information Modeling (BIM) based Approach

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Abstract

Achieving a truly smart and sustainable built environment requires a fundamental commitment to inclusive design, ensuring that spaces are safe and usable for all. However, accessibility is often treated as an add-on instead of an integral design component, and the compliance checks tend to be laborious and inefficient. Building information modelling presents a suitable platform for embedding accessibility assessment early and consistently throughout the design lifecycle. Therefore, this study introduces a simulation system based on Building Information Modelling (BIM) for evaluating and visualising accessibility in architectural environments. A digital building model with distinct parameters such as circulation width, turning radius, ramp slopes, and spatial reachability, facilitating rule-based analysis of adherence to accessibility regulations is created. Following this, simulated movement trajectories for various user demographics, such as wheelchair users or individuals with restricted mobility, are simulated to identify areas that are hard to access, overcrowded, or poorly designed, offering proactive design feedback by uniquely combining regulation analysis with real-time, user-centred simulation. This model would then be used to generate visual outputs such as spatial heatmaps and performance reports, offering immediate feedback and design insights during the various design stages. The proposed methodology offers flexible implementation of different national or institutional accessibility regulations and standards. Hence, the use of this BIM-integrated approach would help architects and planners identify and fix potential barriers in designing spaces that are accessible to all, thereby contributing directly to the social sustainability of the built environment by enabling dignity, independence, and equitable participation.

Keywords: Accessibility, Inclusive Design, Building Information Modelling (BIM), Design Assessment, Simulation, Universal Design, Architectural Design

Highlights

- Accessibility in the built environment is still considered an afterthought in real-world projects.
- Building Information Modelling (BIM) provides an ideal platform for integrating accessibility in the architectural design process.
- This study proposes the use of features in a BIM environment which seamlessly integrate accessibility checks in a regular design workflow.

1 Introduction

Designing a sustainable built environment is not restricted to just environmental responsibility, but also social inclusivity, which can be improved extensively through accessible design. Creating socially sustainable spaces also aligns with the United Nations Sustainable Development Goals, particularly Goal 10 (Reduced Inequalities) and Goal 11 (Sustainable Cities and Communities). However, accessibility continues to be regarded as an add-on, resulting in significant compromises in spatial inclusivity. Guidelines such as the 'Harmonised Guidelines and Universal Accessibility in India' have an extensive list of parameters that could help design accessible spaces (Harmonised Guidelines & Standards for Universal Accessibility in India, 2021). However, such guidelines require long manual audits, which are conducted after the construction of buildings. Thus, a significant research gap exists in ensuring accessibility is systematically integrated into the design process rather than assessed post-construction. This is where digital tools such as Building Information Modelling (BIM) become a potential platform that allows one to follow such guidelines during earlier design stages.

BIM's visualisation features can be an important factor for better design communication, particularly for accessibility (Wu & Kaushik, 2015). Apart from visual communication, BIM can also help in automated compliance checks (Zhang & Ma, 2023). Automated compliance checks can be conducted using accessibility parameter databases, which allow for comparison to the parameters in the BIM model (Rostamiasl & Jrade,2022; Jrade & Valdez, 2012). Geometry-based analysis can also be conducted through digital building models for more in-depth analysis to enhance accessibility features such as wayfinding (Garfias & Namboodiri, 2024).

However, despite BIM's potential, limited studies specifically explore its application for designing accessible spaces. Therefore, this study aims to develop a BIM-enabled framework for accessibility assessment and integration during design. The study introduces accessibility checks in an easily applicable manner during the design stage with impactful parameters such as circulation width, turning radius, ramp, and spatial reachability for different user groups. The BIM-enabled framework presented here helps designers check and integrate key parameters of accessibility early in the design stage, creating spaces that are more inclusive and sustainable.

2 Research Background

2.1 Accessibility in the Built Environment

In a broad sense, accessibility can be defined as "the extent to which products, systems, services, environments and facilities can be used by a population with the widest range of characteristics and capabilities (e.g. physical, cognitive, financial, social and cultural, etc.), to achieve a specified goal in a specified context" (Persson, Åhman, Yngling, & Gulliksen, 2014). Accessibility is intertwined with Barrier-free design, inclusive design and Universal Design. Universal Design (UD) principles aim to make any environment accessible and equitable. (Center for Universal Design, 1997). UD is defined as the design and composition of an environment so everyone can access, understand, and use it to the greatest extent possible, regardless of age, size, ability, or disability. (Centre for Excellence in Universal Design (CEUD), n.d.; Convention on the Rights of Persons with Disabilities (CRPD), 2006; Lid, 2013).

Accessibility is an important feature of a sustainable built environment, but despite this, real-world applications are lacking. A significant reason for this is a lack of exposure and education that architects and other industry professionals have towards the understanding of accessibility in the built environment (Basnak, Tauke, & Weidemann, 2015; Heylighen, 2008; Zallio & Clarkson, 2021).

2.2 Existing Frameworks and Issues

The Harmonised Guidelines and Universal Accessibility in India (2021) offer a compilation of design factors that guarantee accessibility. Similarly, there are many different guidelines available for different countries. These criteria, although comprehensive, are frequently implemented via manual audits, usually conducted post-design or post-construction (Harmonised Guidelines & Standards for Universal Accessibility in India , 2021). This reactive strategy constrains their efficacy in proactively influencing inclusive design results. While many post-design accessibility audit guidelines exist, it is important to note that accessibility is not restricted to just fulfilling a checklist but emphasises the inclusivity of all users. This reinforces the need for integrating accessibility checks within the design process itself to avoid any compromises that could lead to the alienation of some people (Iwarsson & Ståhl, 2003; Preiser & Ostroff, 2001; Zallio & Clarkson, 2021; Zallio & Clarkson, 2022).

Recently, the adoption of Building Information Modelling (BIM) has increased. Various studies and industry practice have shown how BIM goes beyond just geometric representation by providing integration of tools that help in project management, maintenance, building evaluation, etc. (Bryde, Broquetas, & Volm, 2013; Gray, Gray, Teo, Chi, & Lamari, 2013; Gu & London, 2010). Due to such features, BIM offers a digital platform to simulate, evaluate, and include accessibility criteria early in the design phase, assuring consistency throughout the project lifecycle to tackle difficulties in the built environment. BIM is acknowledged as an effective platform for visualising intricate spatial information, improving the communication of accessibility requirements among stakeholders. This can be enhanced by integrating Virtual Reality environments for replicating real-world scenarios (Götzelmann & Kreimeier, 2020; Kładź & Borkowski, 2024; Sampaio, 2017; Wu & Kaushik, 2015). In addition to visualisation, BIM facilitates automated compliance verification by connecting parameter databases to building models, enabling rule-based assessment of accessibility requirements (Rostamiasl & Jrade, 2022; Zhang, Ma, & Broyd, 2023). These computerised verifications diminish human mistakes and enhance the auditing process relative to conventional manual methods (Jrade & Valdez, 2012). Further, the automated compliance checks can also benefit from integrating large language models with deep learning applications for more accurate and holistic analysis. (Chen, Lin, Jiang, & Yi An, 2024).

Additionally, digital building models facilitate geometry-based studies that transcend compliance to encompass functional accessibility elements, including navigation and wayfinding. Digital architectural models can replicate circulation processes and identify potential impediments, enhancing usability and inclusion (Dubey, Khoo, Morad, Hölscher, & Kapadia, 2020; Garfias & Namboodiri, 2024). Collectively, these frameworks illustrate a progressive transition from manual compliance-focused methodologies to technology-integrated, user-centred evaluations. Nevertheless, current research often emphasises legal compliance or user experience, rather than integrating both perspectives into a cohesive design framework. The available study models still focus on post-design assessment, which is not ideal, as any flaws identified in this process would require major redesigns. Furthermore, some design-integration models require complex and specialised tools for accurate analysis. This study aims to integrate such accessibility assessments within a general BIM workflow from early stages of design, which can be consistently used to enhance the accessibility of a particular built environment.

3 Methodology

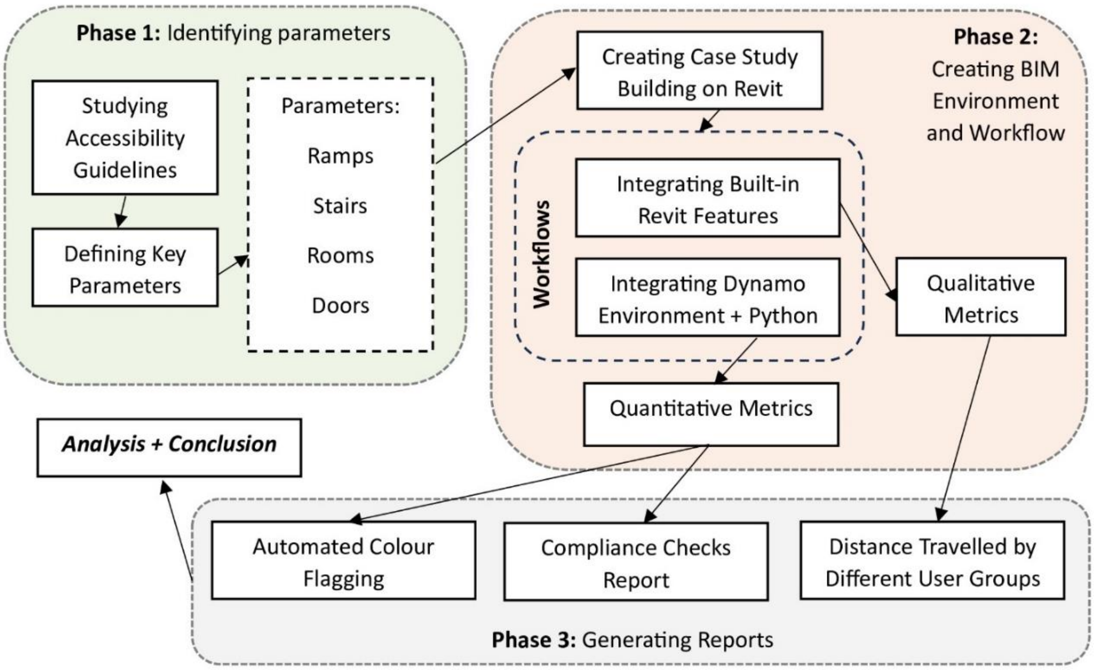

Figure 1. Conceptual Process

The proposed framework begins by studying necessary accessibility guidelines and then extracting key parameters that impact accessibility in a building. This study's selected parameters are: ramps, stairs, rooms and doors. More parameters can be added to this list based on the building model's level of detail and the project's design stage.

A case study building is designed in Revit, wherein the defined parameters are integrated and evaluated. The BIM model is subsequently augmented via two parallel integration methods:

(i) the in-built Dynamo Environment utilising a Python script which defines the compliance limits

(ii) Inherent Revit functionalities guarantee adaptability and user-friendliness within conventional workflows.

The Dynamo environment is utilised to run automated compliance checks, identifying the parameters that do not match the defined limits. For example, if the Ramp slope is supposed to be 1:12 but the model parameter is defined at 1:10, the ramp parameter would fail the accessibility check.

Running the quantitative check would generate a report in an Excel sheet, which lists the dimension value of the key parameters and also shows whether the parameter passed or failed the accessibility check. For better visualisation, the failing parameters are also colour-coded (Red for fail and Green for pass) within the Revit user interface so that the design flaws can be identified with ease. These results make it easier for the designer to make the necessary amends to the building.

In parallel, a qualitative accessibility check can be conducted using Revit's path of travel feature. The path of travel for different users can be defined based on the constraints, such as stairs. These travel paths would give the distance travelled by the different user groups, which can be used to calculate the estimated time taken to go from one point to another.

4 Results

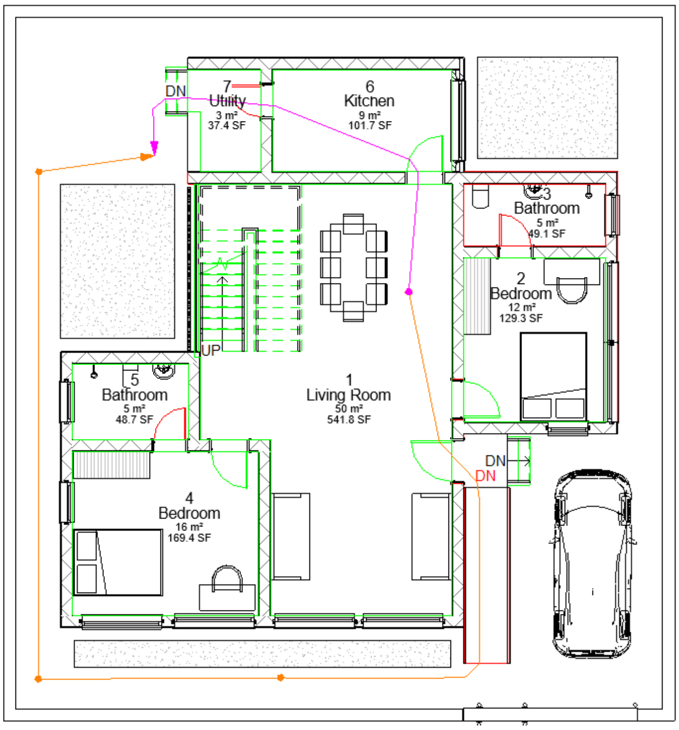

Figure 2. Plan View after running the Dynamo script

Once we run the Dynamo script, we can see that the different parameters have been colour-coded in red and green as shown in *Figure 2*, where red shows that the parameter has failed and green shows that the parameter is within the stipulated limits. The automatically generated Excel sheet shows us why specific parameters failed (*Table 1*).

Table I. Excel Sheet data generated using Dynamo + Python Script.

Type	***Room***	***Check***	***Value***	***Status***
Door	*N/A*	*Width (mm)*	*910*	*PASS*
Door	*N/A*	*Width (mm)*	*810*	*FAIL*
Door	*N/A*	*Width (mm)*	*1010*	*PASS*
Door	*N/A*	*Width (mm)*	*910*	*PASS*
Door	*N/A*	*Width (mm)*	*910*	*PASS*
Door	*N/A*	*Width (mm)*	*810*	*FAIL*
Door	*N/A*	*Width (mm)*	*810*	*FAIL*
Stair	*N/A*	*Riser (mm)*	*150*	*PASS*
Stair	*N/A*	*Tread (mm)*	*250*	*PASS*
Stair	*N/A*	*Riser (mm)*	*150*	*PASS*
Stair	*N/A*	*Tread (mm)*	*250*	*PASS*
Stair	*N/A*	*Riser (mm)*	*156.7*	*PASS*
Stair	*N/A*	*Tread (mm)*	*250*	*PASS*
Stair	*N/A*	*Riser (mm)*	*156.7*	*PASS*
Stair	*N/A*	*Tread (mm)*	*250*	*PASS*
Ramp	*N/A*	*Slope (rise/run)*	*0.1*	*FAIL*
Room	*Living Room*	*MinDim (mm)*	*5862.5*	*PASS*
Room	*Bedroom*	*MinDim (mm)*	*3225*	*PASS*
Room	*Bathroom*	*MinDim (mm)*	*1415*	*FAIL*
Room	*Bedroom*	*MinDim (mm)*	*3725*	*PASS*
Room	*Bathroom*	*MinDim (mm)*	*1725*	*PASS*
Room	*Kitchen*	*MinDim (mm)*	*2325*	*PASS*
Room	*Utility*	*MinDim (mm)*	*1662.5*	*PASS*

[1] Table taken from Excel Sheet.

For this study, the following limits were defined for the different parameters:

- Ramps: Slope (1/x), where minimum value of x = 12
- Stairs: Minimum Tread (mm) = 250, Maximum Riser (mm) = 190
- Rooms: Minimum Turning Diameter (mm) = 1500
- Doors: Minimum Width (mm) = 900

The other accessibility analysis that was conducted is the path of travel check. As shown in *Figure 2*, there are two paths of travel, one traversed by a person without disability (orange line) and another by a person using a wheelchair (purple line). The different travel paths have been defined based on the ramp location, as a person who uses a wheelchair cannot use the stairs. Based on these two travel paths, Revit generates a report showing the distance travelled, allowing us to calculate the time based on built-in parametric calculation features, as seen in *Table 2*. Speed has been defined based on previous studies (Alves et al., 2020; Garfias & Namboodiri, 2024).

Table 2. Path of Travel Analysis

User Group	***Length***	***Custom Speed***	***Calculated Time***
Person without Disability (Purple line)	*33.23*	*0.67 m/s*	*49.6s*
Motorised Wheelchair (Orange Line)	*10.30*	*1.34 m/s*	*7.7s*

[1] Table taken from Revit Schedules/Quantities.

The significantly higher travel time for wheelchair users highlights a significant design flaw, despite compliance with accessibility guidelines. This indicates the need for accessibility checks to extend beyond compliance to improve experiential performance.

5 Discussion

The results provide clarity regarding the barriers that exist within the architectural space and also show improvements required to ensure Universal Design. Such accessibility checks can be implemented at any point of the design stage and do not necessarily require an extensively detailed model for accurate details. The Parameter checks give the architect/engineer clear instructions about the building elements that do not follow the accessibility guidelines. The colour-coded results make it easier to identify the issues, and the generated report gives a better idea of the difference between the designed parameter and the threshold value for that parameter. The parameter checks can be extended for further detailed features, such as furniture, fittings, and other internal geometries. This methodology would reduce the time taken to conduct an accessibility audit significantly and can also ensure accuracy in the results. Ultimately, this would aid the designers in designing a more sustainable building without implementing specialised tools.

The path of travel tool can be efficiently utilised to go beyond compliance with accessibility standards. It can allow us to calculate the time taken by various user groups compared to persons without disability. Currently, no general standards define the limits on the variation in distance and time taken to travel from one point to another. This allows designers to develop a more socially inclusive and sustainable environment based on results from such a qualitative analysis. There is also potential for developing a well-defined framework for path of travel analysis with limits to prevent significant disparities in the time taken to travel the same space by different user groups due to varying abilities.

As shown in this study, a significant limitation for path of travel analysis is that the paths are drawn manually and hence cannot be used to extract multiple data points related to the various travel paths a user can take. This allows further research on integrating automated travel path identification that would simulate the path of travel for various user groups, which could provide important data to help designers make better decisions. There is also a need to study the impact of the significant variation in travel times between different user groups to quantify accessibility requirements.

This study does not aim to propose a strict methodology for conducting accessibility assessment in the built environment. Instead, it introduces tools and techniques for architects, engineers and designers to integrate Universal Design during the design stage seamlessly within a BIM workflow.

6 Conclusions

This study has provided quantitative and qualitative approaches for integrating Accessibility checks in the Building Information Modelling environment. Parameter checks at early design stages can help avoid accessibility compromises in architectural spaces. Conducting path of travel analysis can further emphasise universal design as a concept that is not limited to following basic rules. Building evaluation studies about environmental sustainability have gained traction and found implementation in real-world architecture projects. Similarly, we must address the challenges faced by persons with disabilities, Senior Citizens and all other user groups. Design Integration of accessibility is crucial for creating a truly Smart and Sustainable built environment.

However, this study is not meant to replace manual audits for accessibility; instead, it acts as an aid to designers to help avoid major design flaws that would impact accessibility in the built environment. Further studies can be conducted to create frameworks that could enable BIM-compliant accessibility audits based on as-built BIM models, which could reduce the dependence on manual audits entirely. Integration of large learning models could further enhance the extent of accessibility audit within a BIM model.

Another crucial aspect in improving Universal Design could be integrating participatory design, which can be enhanced by utilising visualisation features of BIM models and Virtual Reality Simulations. Accessibility features related to navigation and wayfinding in the built environment also require further studies for integration in the design process.

Conflicts of Interest
The authors declare no conflict of interest.

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