The Effect of ICT on Sustainability in Building:

Design a Web Application for Elementary School

The Department of Structural, Building and Geotechnical Engineering (DISEG)

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A thesis for the degree of Master of Sciences in Building Engineering

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Dedication

I dedicate this project, which is not only my master’s project but also a part of my life, to my father Ali, mother Nafiseh, and younger brother Hannan. Their love, support, and encouragement have been my strength throughout this journey.

The company of my professors and friends at the Polytechnic of Turin and my country was a pillar to lean on and a wall to rest under their shadow. Special thanks to Valeria and Leila.

And finally, I dedicate this to myself, to the one who actually endured all the hardships, worries, sorrows, disappointments, and stresses of this journey and reached the destination. And never gave up. It was not easy at all, and I understood all of it on the last stair.

Thank you.

Abstract

This thesis addresses a crucial gap in Sustainable Building by developing a web application centered around the user. The application aims to enhance the relationship between individuals and their buildings, with a particular emphasis on sustainability. The study is grounded in the belief that technology and tools can significantly aid the industry in achieving sustainable development objectives.

The study employed a holistic methodology, which included a detailed analysis of a case study, the application of Building Information Modelling (BIM) tools, the design of a web application, and an assessment of the application's effectiveness in relation to the type of building and user characteristics.
The findings indicate that a web application centered on the user can significantly enhance the relationship between individuals and their buildings, leading to an improved user experience and increased sustainability.
The study underscores the need to prioritize users and interoperability in the design of web applications. This approach enhances the functionality and user-friendliness of the applications. It also makes a significant contribution to the field of sustainable buildings. The findings of the study could transform the way users interact with their buildings, encouraging sustainable practices and aiding the Architecture, Engineering, and Construction (AEC) industry in achieving sustainable development objectives.

Keywords : Building Information Modelling, Web Application, Interoperability, Sustainability Goals, User-Friendly Interface, User-focused, User-Experience

Astratto

Questa tesi affronta un gap cruciale nel campo dell'Edilizia Sostenibile sviluppando una web application centrata sull'utente. L'applicazione mira a migliorare la relazione tra gli individui e i loro edifici, con un particolare enfasi sulla sostenibilità. Lo studio si basa sulla convinzione che la tecnologia e gli strumenti possano aiutare significativamente l'industria a raggiungere gli obiettivi di sviluppo sostenibile.

Lo studio ha impiegato una metodologia olistica, che includeva un'analisi dettagliata di un caso studio, l'applicazione di strumenti di Building Information Modelling (BIM), la progettazione di una web application e una valutazione dell'efficacia dell'applicazione in relazione al tipo di edificio e alle caratteristiche dell'utente.

I risultati indicano che una web application centrata sull'utente può migliorare significativamente la relazione tra gli individui e i loro edifici, portando a un miglior "user experience" e a una maggiore sostenibilità.

Lo studio sottolinea la necessità di dare priorità agli utenti e all'interoperabilità nella progettazione delle web applications. Questo approccio migliora la funzionalità e la facilità d'uso delle applicazioni. Contribuisce inoltre in modo significativo al campo dell'edilizia sostenibile. I risultati dello studio potrebbero trasformare il modo in cui gli utenti interagiscono con i loro edifici, incoraggiando pratiche sostenibili e aiutando l'industria dell'Architettura, dell'Ingegneria e della Costruzione (AEC) a raggiungere gli obiettivi di sviluppo sostenibile.

Parole chiave:Building Information Modelling,Web Application, Interoperability, Sustainability Goals, User-Friendly Interface, User-focused, User-Experience

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List of Abbreviations

ICT	Information and Communications Technology
BIM	Building Information Modelling
AEC	Architecture, Engineering and Construction
PWA	Progressive Web Application
WWW	World Wide Web
SDGs	Sustainable Development Goals
GUIs	Graphical User Interfaces
QOL	Quality of Life
LCA	Life Cycle Assessment
APIs	Application Programming Interfaces
APS	Autodesk platform services

Introduction

Background Information

In recent years, remarkable advancements have been observed in building engineering, particularly in sustainable practices (1). These practices are designed to minimize the impact on human health and the natural environment (2). The integration of Information and Communication Technology (ICT) tools has significantly contributed to this progress (3). When combined with technologies like the Internet of Things (IoT), these tools can manage various aspects such as water management, air quality, carbon dioxide emissions, measurement equipment, and energy efficiency (4). A widely used methodology in this field is Building Information Modelling (BIM) (3).

The Architecture, Engineering, and Construction (AEC) industry is increasingly adopting ICT, including web applications (5). These applications serve various purposes, from managing historical buildings (6) to acting as repositories for green building codes (7). However, they are primarily designed for professionals, not end-users.

A notable gap has been identified in user-focused ICT tools that facilitate interaction and involvement between people and their buildings. These tools should not only increase the efficiency of buildings but also accommodate the preferences, ideas, and choices of the people who use them. The problem statement and the purpose of the study can sometimes overlap as they both define the reason for the research. However, they serve different roles in a research proposal. The problem statement identifies and describes the issue that the research will address, while the purpose of the study explains the intent or the 'why' of the research. In this case, the intent is to bridge the gap between people and their buildings by developing user-focused ICT tools.

Problem Statement

Despite the growing use of ICT in the field of building sustainability, it has been found that most existing tools are designed for professionals in the field, not the end-users of the buildings. This lack of user-focused ICT tools limits the potential for interaction between people and their buildings, which is a crucial aspect of achieving sustainability goals.

Purpose and Objectives of the Study

State the Purpose

The purpose of this study is to address this gap by designing a user-focused ICT tool that enhances the interaction between people and their buildings. The aim is to improve the user experience, promote sustainable practices, and contribute to achieving sustainability goals.

List the Objectives

- Identify the needs of end-users: The specific needs and preferences of end-users in several types of buildings (offices, gyms, schools, etc.) are to be understood.

- Design the ICT tool: A web application is to be developed that allows users to share their ideas and feelings about their buildings. The tool should be easy to use and accessible to a wide range of users.
- Integrate with BIM: It is to be ensured that the tool can work in conjunction with Building Information Modelling (BIM) for monitoring and maintenance aspects.
- Create a user-friendly interface: The tool should provide an intuitive and easy-to-use interface that can be implemented by any user. It should also facilitate user participation in numerous ways such as answering questions, participating in polls, commenting, or reposting. All these user feedback and interactions can then be gathered and displayed on a dashboard. This data can be used to better respond to people's needs and preferences regarding their buildings
- Assess the tool in a real-world setting: A primary school is to be used as a case study to evaluate the tool and gather feedback from end-users.

Research Questions and Hypotheses

Research Questions

This study aims to answer the following research questions:

- How can Information and Communication Technology (ICT) in a web application be chosen and designed to improve interaction between end-users and their buildings?
- How can the design of a web application be tailored to the specific needs and characteristics of different end-users (like students, maintenance staff, managers) and several types of buildings, considering factors such as age-appropriate interfaces (like game-like interfaces for primary school students)?
- How does this tailored design of the web application contribute to sustainability goals and practices?
- How can interoperability between different software from different disciplines be achieved for the web application?

Hypotheses

Based on these research questions, the study proposes the following hypotheses:

- The choice and design of ICT in a web application can significantly improve the interaction between end-users and their buildings.

- A web application designed with consideration to the specific needs and characteristics of different end-users and types of buildings can significantly enhance user participation and interaction.
- A tailored design of the web application contributes significantly to sustainability goals and practices by enhancing user interaction and participation.
- Interoperability between different software can be achieved through specific format conversions and exports, enhancing the functionality and user-friendliness of the web application.

Methodology

This research employs a multi-faceted methodology to explore the interaction between end-users and their buildings through a user-focused web application.

The methodology includes:

- Literature Review: An exhaustive review of the existing literature on the application of Information and Communication Technology (ICT) in sustainable buildings, user interaction, and sustainability practices was conducted. This review informed the design and development of the web application.
- Integration with Building Information Modelling (BIM): The web application was integrated with BIM tools to ensure compatibility with current industry practices. Various formats, converters, and exports were evaluated to identify the most efficient and user-friendly solutions.
- Web Application Design: The design of the web application considered the specific needs of various end-users and building types. A range of platforms and methods were assessed to identify the most effective approach.
- Efficiency Evaluation: The final achievement was checked through different hypotheses to assess the efficiency of the web application. This step involved running multiple tests and simulations to evaluate the performance and effectiveness of the application under various conditions.

This methodology provides a comprehensive approach to understanding how a user-focused web application can enhance the interaction between people and their buildings, contribute to sustainability goals, and improve user experience. The findings from this research could have significant implications for the design of web applications in the context of sustainable buildings.

Significance of the Study

The significance of this study lies in its potential to revolutionize the way users interact with their buildings. By developing a user-focused web application that enhances user participation and interaction, this research could contribute to improved user experience and increased sustainability. The study also explores the influence of building function and user characteristics on the design of the web application, providing valuable insights for future development in this field. Furthermore, by achieving interoperability among different systems, this research could enhance the functionality and user-friendliness of the web application, making it a valuable tool for various stakeholders in the building industry.

The states of the art

Overview

The Architecture, Engineering, and Construction (AEC) industry is crucial in achieving sustainable development goals (8). This industry influences various aspects of society, the economy, and the environment (9). Technology and tools have improved the industry's ability to design, construct, and manage buildings sustainably (10).

Information and Communication Technology (ICT) has revolutionized the AEC industry, particularly in building design and management (3). Tools like Building Information Modelling (BIM) (11), web applications (7), and the Internet of Things (IoT) (12) are powerful aids in achieving sustainability in the built environment.

Web applications are particularly promising in enhancing the efficiency and effectiveness of building design and management (5). They provide a platform for real-time data collection, analysis, and visualization, enabling informed decision-making that enhances building performance and sustainability (5).

Conceptual Framework

This thesis revolves around the intersection of the AEC industry, sustainable development, and ICT. The belief at the heart of this framework is that technology and tools can significantly enhance the industry's ability to achieve sustainable development goals (10).

BIM, for example, allows for the creation of digital representations of the physical and functional characteristics of buildings (11). This leads to better collaboration and communication among stakeholders, improved decision-making, and better project outcomes.

Web applications provide a platform for managing and visualizing building data. They enable real-time monitoring and control of building systems, leading to improved energy efficiency, and reduced environmental impact (5).

However, there is another crucial intersection that needs to be addressed - the intersection with the end user. While much of the focus has been on experts and stakeholders, there is a need for tools like web applications that allow people to participate in their building's management in various aspects and increase their interaction.

An easy-to-use solution that does not require expertise and can be used by people at diverse levels could significantly enhance user participation and acceptance of sustainable practices. But the question remains, how can this be achieved?

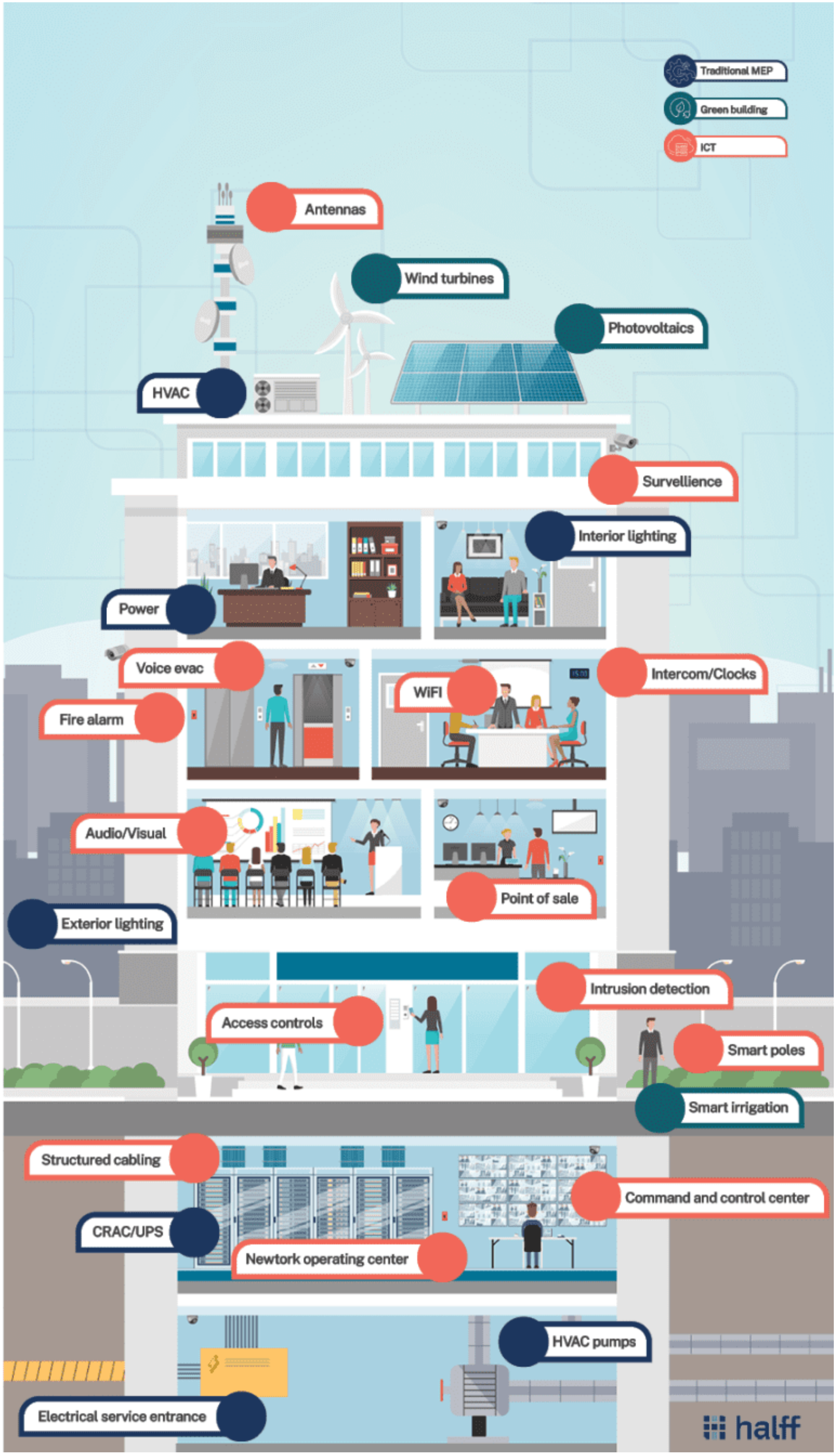


*Figure 1 ICT contribution in the building **Halff** is one of the nation's top engineering consulting firms.*[i]

About WWW[ii]

The World Wide Web has evolved significantly since its inception, transitioning from a static, read-only platform (Web 1.0) to a dynamic, interactive one (Web 2.0). This transformation has profound implications for how users interact with web content and with each other.

Web 1.0, also known as the “read-only web,” was characterized by static websites where users were primarily consumers of information. Interaction with the web content was limited, and users could not contribute their own content or collaborate with others.

The advent of Web 2.0, often referred to as the “read-write web” or “participative web,” marked a paradigm shift in the web’s functionality. Web 2.0 emphasizes user-generated content, ease of use, participatory culture, and interoperability. In this new web era, users are not just passive consumers of information, but active contributors and creators. They can interact with web content, contribute their own, and collaborate with others.

A key product of this Web 2.0 era is the web application. Web applications are dynamic websites that offer interactive services, such as social networking, content sharing, online shopping, and much more. They are accessed through a web browser and do not require downloading or installation like traditional software applications.

There is also Web 3.0 represents the third generation of the World Wide Web and is currently under development. It envisions a decentralized web, shifting the paradigm from centralized platforms to decentralized and anonymous ones. This new era of the web is all about reading, writing, and owning content. Each evolution of the web, from Web 1.0 to Web 3.0, has significantly influenced how users interact with web content and with each other. These changes have had profound implications, transforming the way is used and experienced the internet.

Synthesis of Findings

In the pursuit of understanding the current state of web applications in the AEC industry, three significant research papers were analyzed. These papers each present a unique approach to integrating ICT tools, specifically web applications, in various aspects of building management. The following table provides a comparative analysis of these papers.

The table provides a comprehensive comparison of the three different web applications currently used in the building industry. Each application has its unique strengths and focus areas, demonstrating the versatility and potential of web applications in enhancing building management and sustainability. However, a common thread across all three is the focus on expert users, leaving a gap in applications designed for end-users.

Paper	Objective	Methodology and Tools	Function	Interface	Data Domain	User Domain
Engaging Building Automation Data Visualisation Using Building Information Modelling and Progressive Web Application (5)	Enhance the Building Lifecycle Management (BLM) processes by integrating Building Information Modelling (BIM) and assets database	Framework for the efficient development of an interoperable visualization of a building's "digital twin" through an intuitive interface	Gather relevant metrics and constant feedback from buildings' occupants, select meaningful data, process it, and display it to improve the Facility Management (FM) process	Progressive Web Application (PWA)	Building indoor climate metrics and architectural BIM models	Facility managers, building occupants, and stakeholders involved in BLM
Development of a Web Application for Historical Building Management through BIM Technology (6)	Develop a management system for the maintenance and conservation of historical buildings	Creation of a web-based IT infrastructure using advanced technologies, Autodesk Revit software, Microsoft SQL Server, and C# through Visual Studio 2015	Provide automated and digitized information connected to the 3D-BIM model of the building	Web-based application interface	Management of historical buildings (Building Maintenance, Conservation and Restoration, Data Management)	Conservationists, historians, and facility managers of historical buildings
Development of web-based information technology infrastructures and regulatory repositories for green building codes in China (iCodes) (7)	Support green building standards	Development of iCodes, a web-based IT infrastructure, using advanced technologies and an XML-based data infrastructure	Serve as a repository for educational material on the building delivery process	Web-based application interface	Green building practices, particularly energy efficiency	Professionals involved in the building industry who are interested in or responsible for implementing green building standards and practices

Figure 2 The table of Comparison the Web Applications in Building Management

Opportunities for Further Research

The analysis of the three web applications reveals a significant gap in the current landscape of ICT tools in the AEC industry - the lack of user-friendly applications that promote the active participation of end-users in their building's management and sustainability. This presents an exciting opportunity for further research.

Future research could focus on the development of a web application designed specifically for end-users, not just experts or stakeholders. This application could provide an intuitive interface and user-friendly features that allow end-users to participate actively in various aspects of building management. It could include features for real-time monitoring and control of building systems, feedback mechanisms for occupants, and educational resources on sustainable practices.

Moreover, the application could leverage the power of IoT devices, machine learning algorithms, and other advanced technologies to provide personalized recommendations and insights to the users, further enhancing their interaction with the building and promoting sustainable practices (13).

Concluding Remarks

In conclusion, the integration of ICT tools, particularly web applications, in the AEC industry has the potential to significantly enhance building management and sustainability. However, there is a need for more user-centric applications that promote the active participation of end-users in their building's management.

This thesis aims to explore this opportunity, focusing on the role and potential of user-friendly web applications in the AEC industry. The goal is not just to enhance the efficiency and effectiveness of building management but also to empower end-users, promoting a culture of sustainability in the built environment.

Methodology

Description of the research design and methods

The purpose of this methodology chapter is to outline the approach taken to develop a user-focused web application aimed at achieving two primary goals: enhancing sustainability and improving the quality of life for end-users.

Recognizing that a generic solution would not suffice, the methodology is designed around the principle of customization. The web application is tailored to the specific needs and characteristics of the end-users and the functions of the buildings in which it will be implemented. This customization is crucial to ensure the effectiveness of the application in its intended setting.

The first step in the methodology involves a comprehensive examination of the case study. This includes an in-depth analysis of the end-users' characteristics and the building's functions. With this understanding, it is determined the potential features and functions of the web application.

This chapter aims to answer research questions.

- How can Information and Communication Technology (ICT) in a web application be chosen and designed to improve interaction between end-users and their buildings?
- How can the design of a web application be tailored to the specific needs and characteristics of different end-users (like students, maintenance staff, managers) and several types of buildings, considering factors such as age-appropriate interfaces (like game-like interfaces for primary school students)?
- How does this tailored design of the web application contribute to sustainability goals and practices?
- How can interoperability between different software from different disciplines be achieved for the web application?

The subsequent sections of this chapter will delve into the specifics of the methodology. This includes the design and development process of the web application, the integration with Building Information Modelling (BIM) tools, the collection and analysis of user participation, and the evaluation of the web application's impact on sustainability and user quality of life by testing different hypothesized situations.

By detailing the methods used in this research, this chapter provides a roadmap for how this aims to answer the research questions and achieve the goal of creating a user-focused web application that enhances the interaction between people and their buildings, contributes to sustainability goals, and improves user experience.

Case Study

The case study for this research is a primary school located at VIA PELLANDA, 28036 CRODO (VB). The school has a total of forty students, divided into three classes, with an average of approximately 13_14 students per class.

The school building has a rich history, dating back to the 1920s or 1930s. Over the years, the building has undergone numerous changes and is not in its original form. Despite these changes, the building continues to serve its purpose as a primary school, providing education to the children of Crodo.

Crodo is a village situated in the north-west of Italy, in the lush Italian Alps amongst vineyards, famous rock gorges, and historic castles. The natural beauty and tranquility of the area provide an ideal environment for a school.

Figure 3 SCUOLA ELEMENTARE DI CRODO [iii]

The design of the web application for this case study will consider the unique characteristics of the school, its students, and its location. The application will be tailored to meet the specific needs of the end-users (students(age 6_9) and their parents, staff, and managers) and the functions of the school building. This customization is crucial to ensure the effectiveness of the application in its intended setting.

Figure 4 Exterior view of the building[1]

Web Application Characteristics

The characteristics of a web application are dependent on the function of the buildings and the users of it. In this context, there are three groups of people involved:

Web developers and BIM experts: These professionals are responsible for the technical development and maintenance of the web application.

School staff: This group ranges from managers to maintenance personnel who interact with the application in their daily operations.

Students and their families: The primary users of the application, who utilize it for educational purposes and communication.

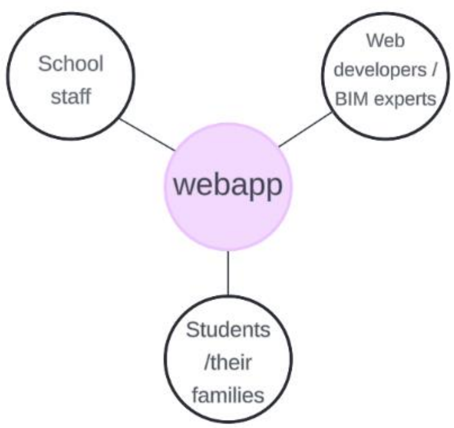


Figure 5 the diagram of web app connections

[1] Photo by drawing to the future laboratory at politecnico di torino

Given that the building in question is a primary school, the web application can contribute to several sustainability goals. Specifically, the web application, designed for a primary school, can contribute to several of the 17 Sustainable Development Goals (SDGs) established by the United Nations. Here is how (14):

Quality Education (SDG 4): The application can enhance the quality of education by providing a platform for feedback and comments, allowing for continuous improvement based on user input. The questionnaire feature can be used to gauge satisfaction levels among students, parents, and staff, providing valuable data to inform decision-making.

Good Health and Well-being (SDG 3): The 3D view of the school can be used to educate students about emergency routes and safety procedures, contributing to a safer and healthier environment.

Sustainable Cities and Communities (SDG 11): The 3D view can also be used to familiarize new students and staff with the layout of the school, promoting inclusivity and accessibility.

Partnerships for the Goals (SDG 17): By facilitating communication and feedback between various stakeholders (students, parents, teachers, administrators), the application fosters a sense of community and partnership.

While the application does not directly control energy usage or other resource consumption, it can still promote sustainability in other ways:

Responsible Consumption and Production (SDG 12): The application can host educational content about sustainability practices, encouraging users to make more environmentally friendly choices.

Climate Action (SDG 13): The platform can be used to raise awareness about climate change and the importance of sustainable practices.

Figure 6 The 17 Sustainable Development goals by 2030

Every action towards sustainability counts, and this application can play a significant role in promoting these goals within the school community.

This research aims to explore these characteristics and their impact on sustainability in the context of a primary school web application. This study tried to provide insights into how web applications can be designed and utilized to promote sustainability in educational institutions.

Interoperability Analysis

In the context of this thesis, an exploration is being conducted into the overlap between two distinct domains: the Information and Communication Technology (ICT) world, represented by Web 2.0 and web applications, and the Building Information Modeling (BIM) world, represented by the architectural, engineering, and construction (AEC) data of the school building.

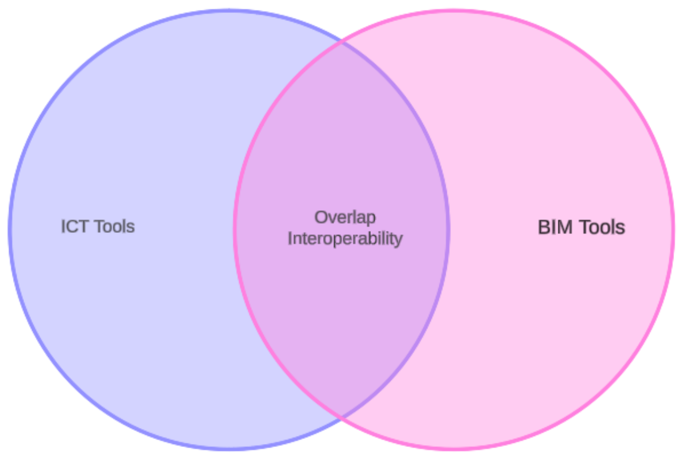


Figure 7 The Interoperability between BIM and ICT Tools

The BIM part of the methodology begins with the input data. This data could include information about the school building, user requirements, sustainability goals, etc. This data is crucial as it forms the basis for the interactive features of the web application.

The input data is processed within an ecosystem, which could represent the overall system or platform where the BIM data is managed and processed. This ecosystem ensures that all the relevant data is available for the subsequent stages of the workflow.

The next step involves process optimization and control. This step is based on stakeholder roles and responsibilities and could involve various stakeholders such as architects, engineers, contractors, and facility managers. The process is optimized and controlled to ensure that the BIM data accurately represents the school building and meets the requirements of the web application.

Communication and collaboration platforms facilitate communication and collaboration among the stakeholders. They ensure that everyone involved in the project has access to the latest information and can contribute to the decision-making process.

The data that is stored after being processed in the ecosystem is referred to as stored data. It includes environments, existing drawings/CAD, existing 3D models, territorial maps, geospatial survey, and documentation. This stored data is used in the development of the web application.

The central part of the workflow is the BIM ENGINE, which could represent the main software or platform where the 3D model of the school building is created and maintained. It integrates with various other software tools to provide a comprehensive and accurate representation of the school building.

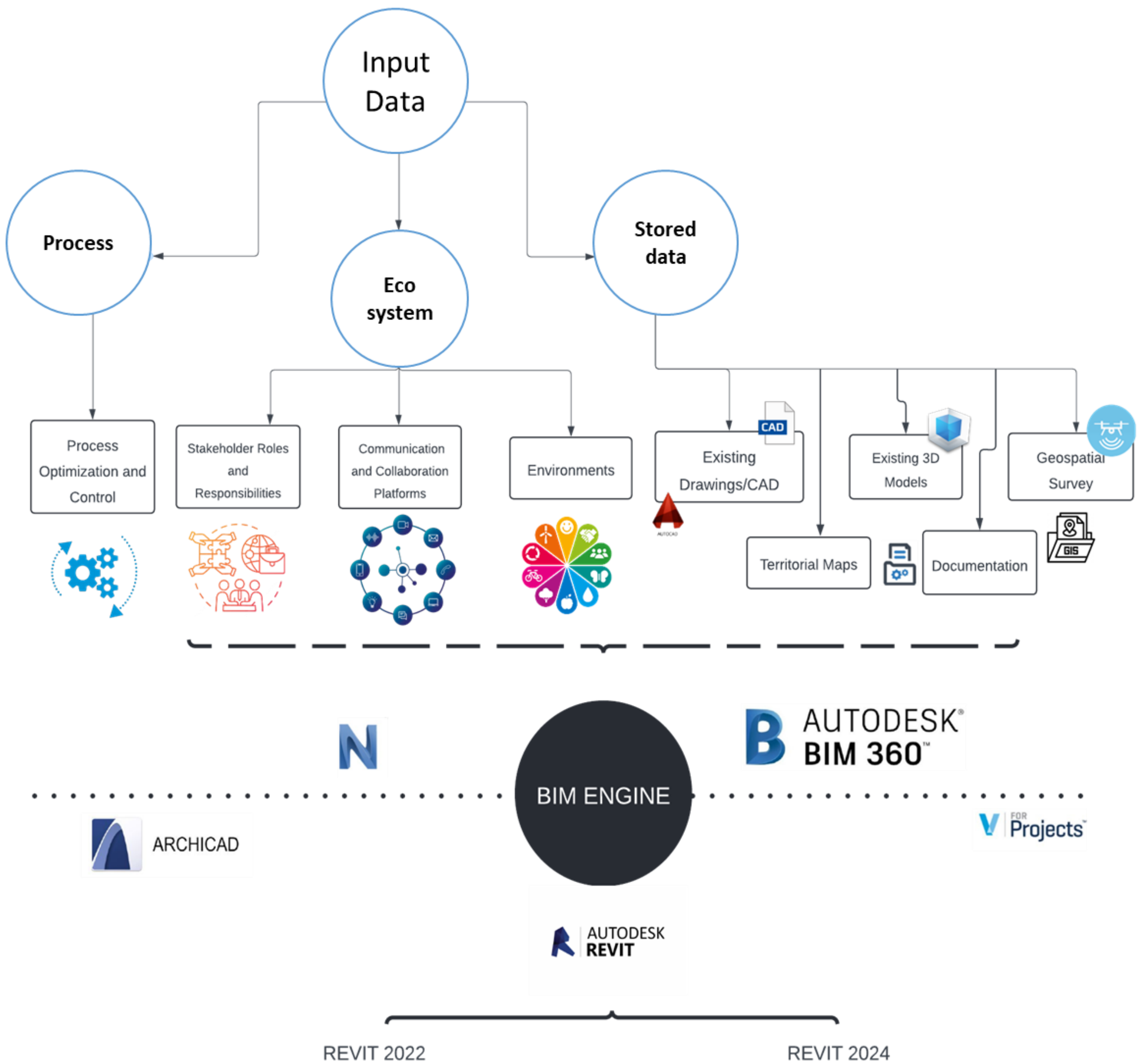


Figure 8 BIM process workflow (15)

In this project, Autodesk Revit is used as the BIM engine. Revit is a powerful BIM software that allows for detailed modeling of buildings and efficient management of building data. Two versions of Revit, 2022 and 2024, have been assessed. These versions were chosen based on their compatibility with the other software tools used in the project, as well as their ability to support the specific requirements of the web application.

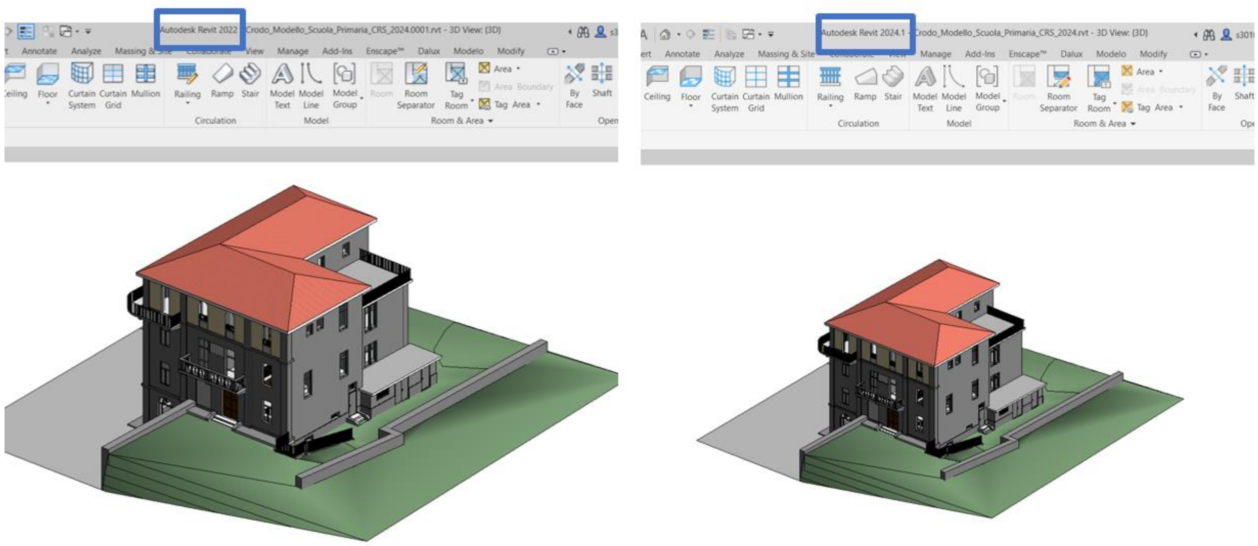


Figure 9 The BIM of school in Revit 2022 and 2024

After preparing the BIM file using a BIM engine, the next step is the process of describing testing the interoperability of Building Information Modeling (BIM) outputs for integration into the ICT world. This is a key step to be sure that the data generated from BIM engines like Revit can be effectively used in various ICT tools and in this case, be standard for web format (web-based application).

The primary objective of this experiment is to evaluate the potential conditions required for rendering 3D models in a web application. A crucial element of this interoperability is the implementation of Graphical User Interfaces (GUIs).

GUIs offer an intuitive platform for users to engage with their building applications. They enable users to visualize and manipulate the data encapsulated within BIM files (16). This aspect is especially significant for web applications, where user engagement is influenced by ease of use and accessibility.

Initially, an assessment is conducted on the web application’s ability to manage familiar formats for displaying 3D files[iv]. Four types - GLB, gltf, OBJ, and JSON - have been identified, each exhibiting unique capabilities. This assessment aids in understanding the most effective way to present 3D models in a web environment.

To achieve a uniform format from the export of the BIM engine, there are crucial steps that necessitate a specific approach. This is done to attain a conversion level that can utilize potential tools for evaluating the output (17).

The testing was performed on both the 2022 and 2024 versions of Revit. This facilitates a comparative analysis of features and compatibility across different software versions.

The procedure commences with two primary strategies:

Plugin Approach: This approach involves the use of plugins to export or convert files from Revit. The plugins tested in this process include Modelo[v], Enscape[vi] , and Dalux[vii]. Each of these plugins has its own unique features and capabilities. After the files are exported or converted using these plugins, they are then tested for compatibility with web standards.

Export File Approach: This approach involves exporting files directly from Revit in various formats, including IFC[viii], RVT, and OBJ. Notably, the OBJ format is a new feature available from Revit 2024 onwards, which adds another option for data export. These files are then processed using various tools to convert or export them into different formats. This allows for greater flexibility in how the data can be used, as it can be converted into several formats.

The final formats are then evaluated for their compatibility with web standards. This is indicated by green (compatible) or red (incompatible) markers. If a format is found to be incompatible, it remains within the BIM domain and does not overlap with the ICT world. This ensures that only compatible data is used in ICT applications, thereby preventing potential issues related to data incompatibility.

This process is a comprehensive method for ensuring that BIM outputs can be effectively integrated into the ICT world. It considers several factors, including the specific features of different versions of Revit, the capabilities of various plugins, and the requirements of web standards.

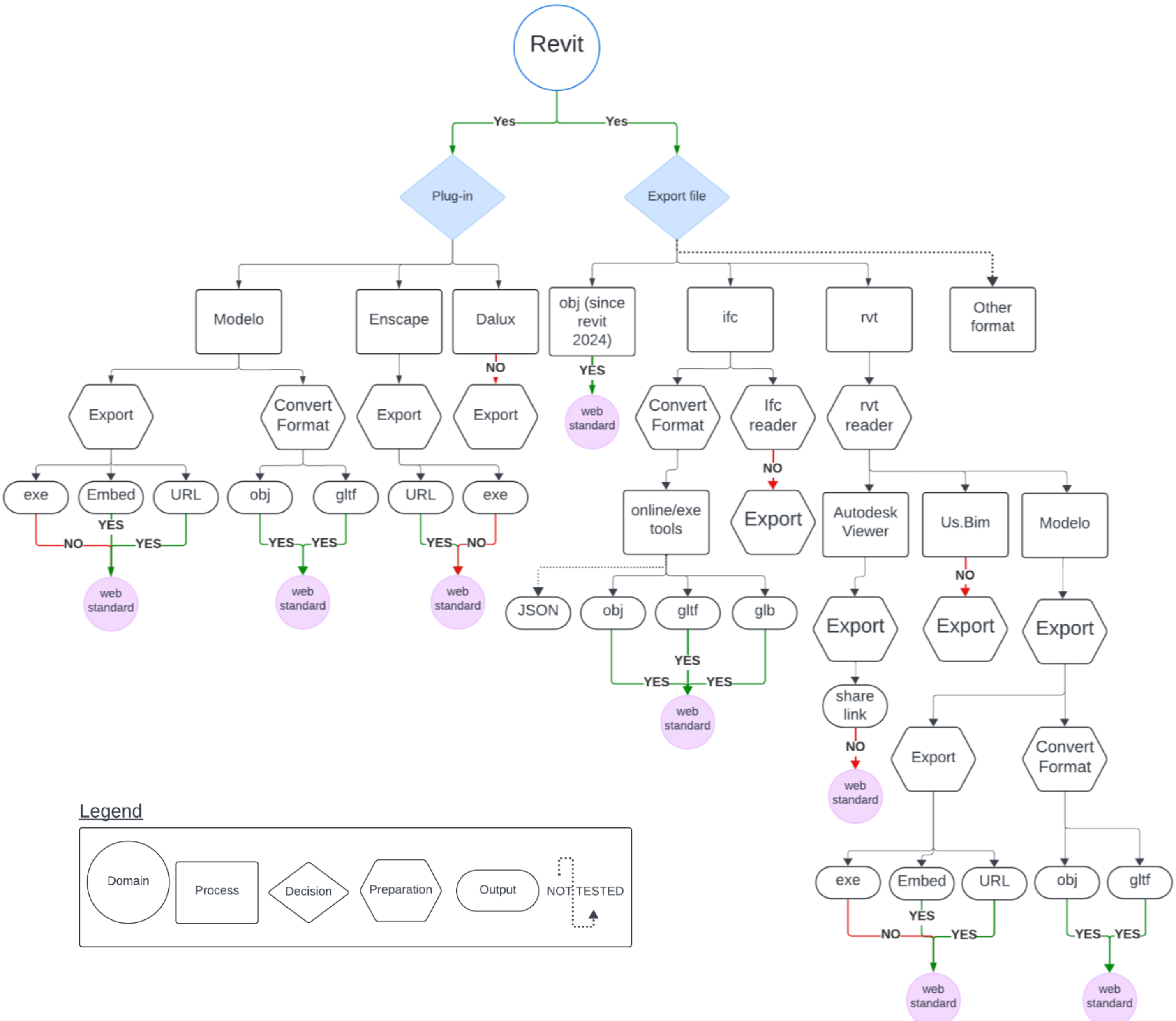


Figure 10 BIM output test for interoperability

The results of the tests conducted for this research have yielded various formats, most of which have successfully met the criteria for web standard compatibility. And some are not.

The .exe format, while not typically used for 3D models, can be utilized to create standalone applications that display 3D models. However, due to security concerns and compatibility issues across different operating systems, this format is not deemed suitable for web applications.

The .obj format[ix] is a widely supported 3D model format across different platforms. It is a simple, open format that can represent 3D geometry, making it a popular choice in 3D printing and computer graphics. However, it lacks support for more advanced features such as animations or complex materials.

The .gltf[x] format, or GL Transmission Format, is a royalty-free specification designed for the efficient transmission and loading of 3D scenes and models by applications. It aims to minimize both the size of 3D assets and the runtime processing needed to unpack and use those assets. Due to its potential to become a universal 3D model format, it is often referred to as the “JPEG of 3D”.

The glb[xi] format is a binary version of the gltf format, encapsulating all the resources in one file. It is a versatile and widely used 3D file format that has gained significant traction in recent years. It is designed to minimize both the size of 3D assets and the runtime processing needed to unpack and use those assets. It supports motion and animation without sacrificing quality, a crucial factor for dynamic 3D content.

Two formats that stand out in this research are the URL and Embed formats. Unlike the .obj and .glb formats, which are file-based, the URL and Embed[xii] formats operate differently. They are not files per se but rather references to the 3D model stored on a BIM-based platform. When a URL or Embed format is used, the 3D model is not directly embedded in the web application. Instead, the web application displays the model by referencing it from the BIM-based platform where the model is stored. This method allows for efficient data management and quick loading times, as the heavy 3D model data does not need to be loaded directly onto the web application.

Each of these formats has its strengths and weaknesses, and the choice of format depends on the specific requirements of the web application and the nature of the 3D models being used. In the next chapter, it will delve into a detailed evaluation and discussion on the quality and performance of each format.

Web Application Design

In the pursuit of creating an interactive and engaging web application for students, the transition from Building Information Modelling (BIM) output to web input is a critical step. This web application aims to provide an immersive 360-degree view of the school building, offer essential information about the school, and facilitate communication between students and the school administration. It also seeks to promote sustainability awareness among students, thereby aligning with the principles of sustainable building.

Designing this web environment involves choosing the right development methodology. There are several methodologies available, each with its own strengths and considerations:

Traditional Coding: This approach offers the most flexibility and control, allowing for highly customized applications. However, it requires significant coding knowledge and experience.

Low-Code Development: This approach accelerates the development process by providing a visual interface and pre-built components that can be customized with minimal coding. While it requires less coding knowledge, it may not offer as much flexibility as traditional coding.

No-Code Development: This approach allows users to design applications entirely through a visual interface, without needing to write any code. It is the fastest and easiest method, but it may not be suitable for more complex applications.

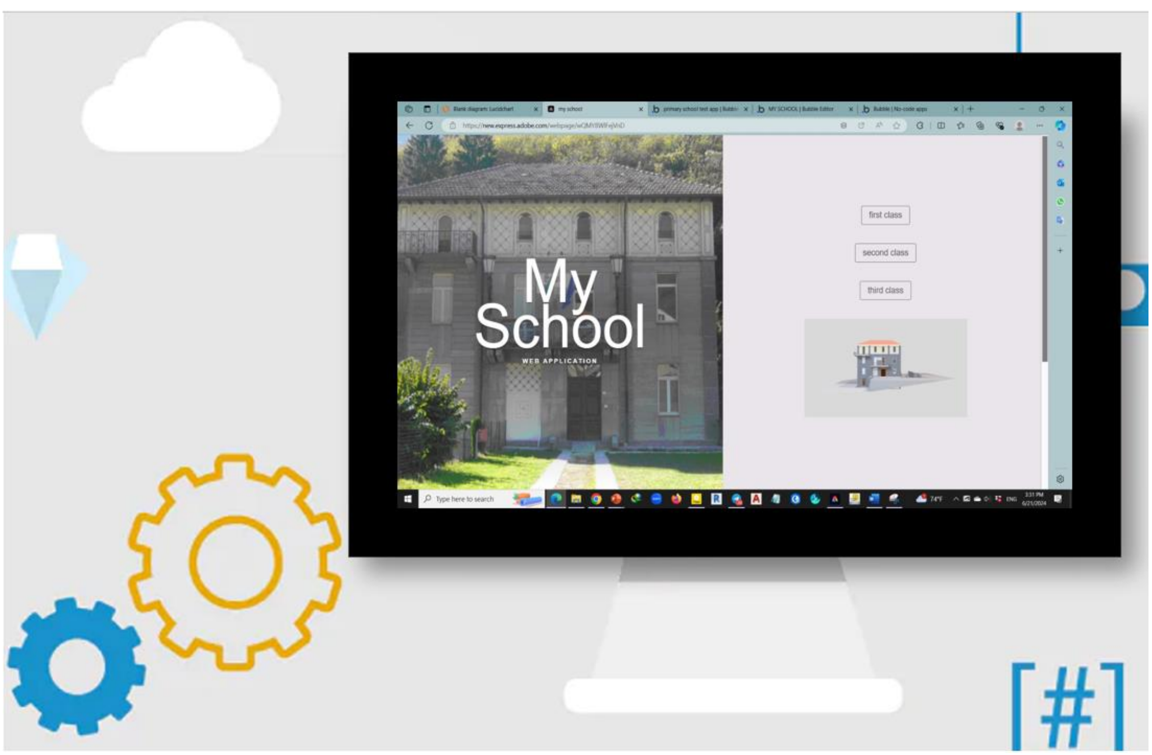


Figure 11 The first look of the school web application

	Zerocode (No-Code) Platforms	Low-Code Platforms	Traditional Coding Platforms
Development Approach	Visual drag-and-drop interfaces, no need for code	Visual interface with option for code customization	Manual coding using various programming languages
Target User Base	Non-technical users (citizen developers, business analysts)	Wide range of users (non-technical users to experienced developers)	Highly skilled developers with in-depth knowledge of programming languages, methodologies, and frameworks
Customization	Limited, pre-built components and templates	Balance of pre-built components and code customization	Complete control, highly tailored solutions
Advantages	Rapid development time, cost-effective, accessible to non-technical users, lower technical debt	Faster development time compared to traditional coding, suitable for a wide range of user skill levels, better suited for custom solutions than Zerocode platforms	Complete control over customization, wide range of programming languages, methodologies, and frameworks available for use
Disadvantages	Limited customization and flexibility, potential vendor lock-in, may not be suitable for complex, unique, or highly specialized solutions	May still impose limitations on customization compared to Traditional Coding, a higher learning curve for non-technical users than Zerocode platforms	Slower development times and higher costs, requires extensive knowledge in programming languages and various technologies, which leads to a higher learning curve
Difficulty Level	Easy	Medium	High
Work Distribution	Mostly individual work, but can also be used in team settings	Suitable for both individual and team settings	Mostly team-based, especially for larger projects
Knowledge Requirements	Basic computer skills	Basic computer skills and some coding knowledge	Extensive knowledge in programming languages and various technologies
Software/Hardware Requirements	Internet connection, modern web browser	Internet connection, modern web browser, sometimes specific development environments	Specific development environments, compilers, libraries, and frameworks
Examples	AppMaster.io, Wix, Bubble, Webflow	OutSystems, Mendix, Appian	Python, Java, C++, JavaScript

Figure 12 The comparison table of different methods of web design [xiii,xiv,xv]

Given that this thesis is an individual project carried out by a non-web builder expert, the No-Code Development approach was chosen. This decision was based on several factors:

Ease of Use: No-Code platforms are designed to be user-friendly, making them accessible to individuals without extensive coding knowledge.

Speed of Development: No-Code platforms allow for rapid development and deployment of applications, which is crucial in a time-sensitive project.

Focus on Functionality: Using a No-Code platform allows the focus to be on the functionality and user experience of the application, rather than the technicalities of coding.

The choice of No-Code Development aligns with the project's objectives and the developer's expertise, paving the way for an effective and efficient development process. The goal is to create a web application that enhances educational experience, promotes sustainable behaviors, and improves interaction between individuals and their school building.

Specific No-Code Platform: For the development of this web application, Bubble has been chosen for this study. Bubble was selected for its extensive functionality and the availability of a wide range of libraries and plugins that enhance the application's capabilities. It offers a user-friendly interface and a robust platform for building interactive, multi-user apps without needing to write code.

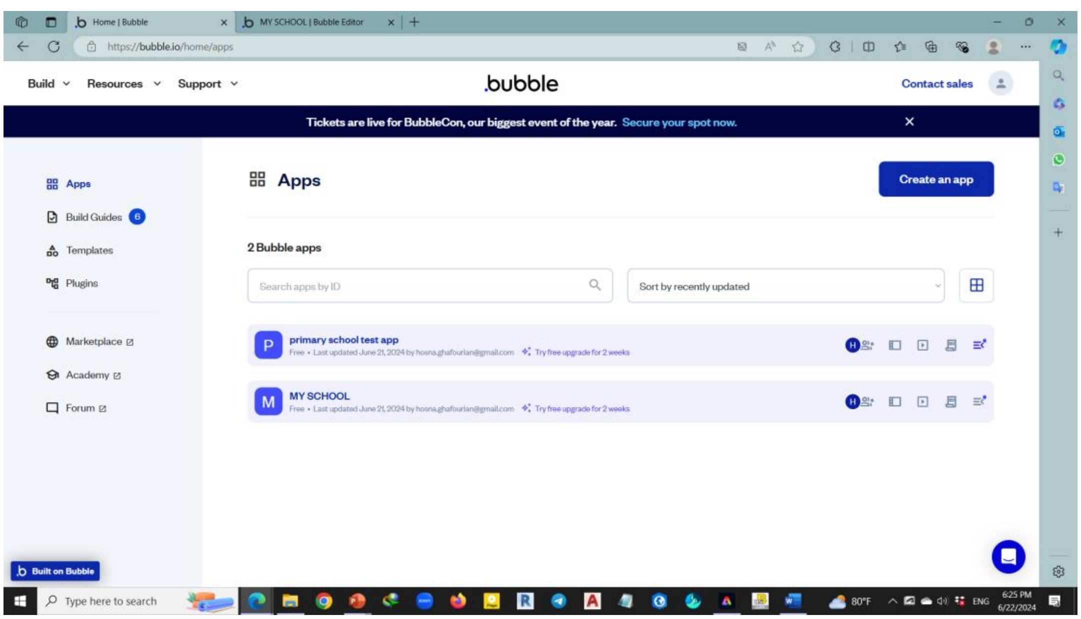


Figure 13 Bubble.io workspace[xvi]

The primary objective of this thesis, enhancing the interaction between users and their building, is sought to be achieved through the integration of various tools into the web application using Bubble. These tools, including features such as polls, feedback mechanisms, and question boxes, are integrated, considering different conditions from financial and instructional perspectives. They enable diverse ways for users to contribute. However, the successful operation of the 3D model within the web application is the primary focus, even though other tools have their own processes for operation.

An appropriate API, necessary for displaying 3D models, has been identified for web viewing. However, additional solutions are required for its implementation in this web application. Consequently, specific plugins and libraries are explored to exhibit the desired features in this web application. Various options are suggested by Bubble for this purpose, each with different financial conditions. However, the workflow logic is found to be almost identical across all options, with variations in speed, graphics, workload, and quality.

To evaluate the main workflow, HTTP requests are initiated for the 3D object**. This step requires cloud space to run the 3D object**, whether using HTTP or another API. The primary distinction among all tools lies here. **The goal is not merely to save the file but to perform operations in the cloud**. Different APIs designed for this process either have their own cloud or are automatically linked with other tools.

The next step involves finding the right platform to define the URL for viewing the 3D model. Several platforms commonly used for hosting 3D models include Sketchfab, Google Poly, Microsoft Remix 3D, and Thingiverse.

Once the 3D model is uploaded, these **platforms typically provide a way to share the model, usually through a 'Share' or 'Embed' button**. This **generates a URL pointing directly to the 3D model, which can be used to share the 3D model**. Anyone with the URL should be able to view the model using a compatible browser or software. It is notable that the exact process may vary depending on the platform chosen to host the 3D model. Always refer to the specific instructions provided by the platform. In this case, Sketchfab is chosen for use.

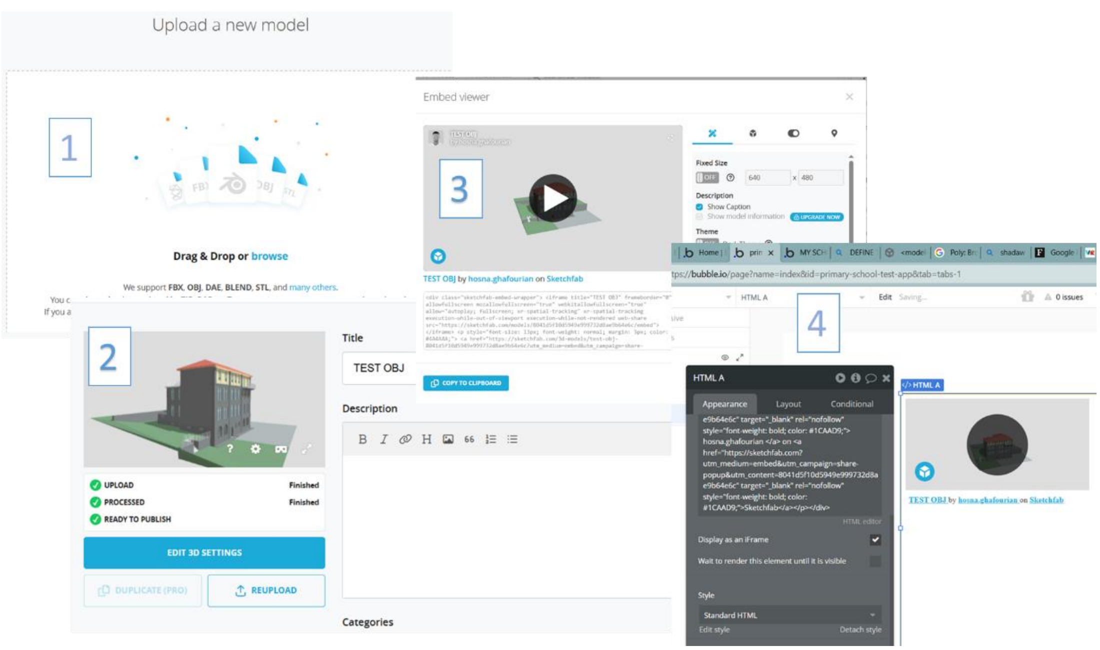


Figure 14 The process of uploading 3D models in a web application

1:upload the 3D file in the chosen platform

2:displaying the 3D model

3:generating the URL link to share

4:use in HTTP for webapp

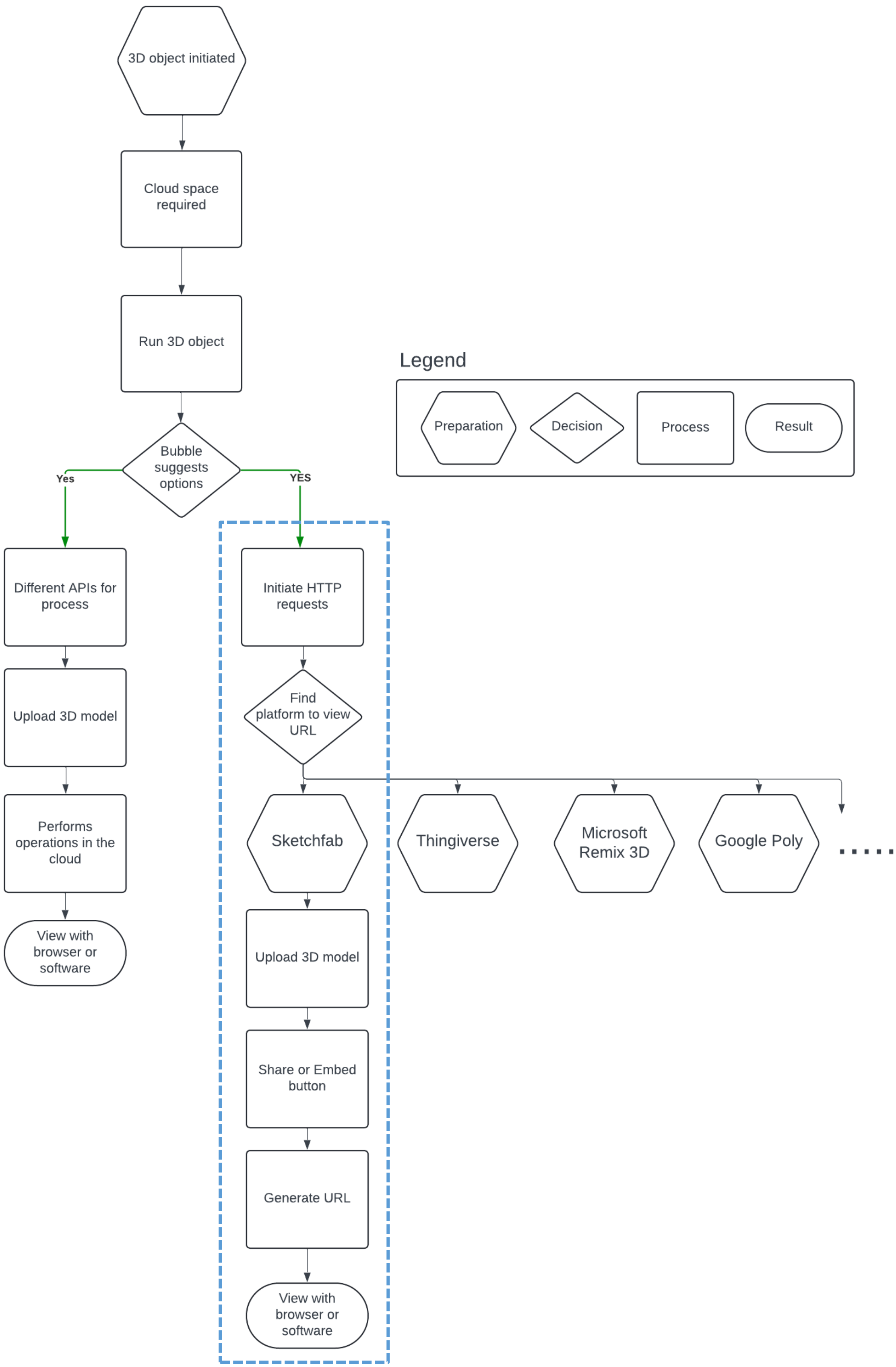


Figure 15 The process diagram to display 3D obj in the web app with highlighted followed workflow

Evaluating the web app efficiency by different hypothesized situations

The web application is designed to offer a variety of functions tailored to the needs of the users and the building. A few key functions are selected for this study, believed to have the most impact on the students' Quality of Life (QOL) and the building's efficiency.

The first set of functions involves navigating through the building using an embedded model. This is designed to aid in familiarizing students with the school building, guiding them to their classes, and providing a platform for them to comment or report on building issues.

To evaluate the effectiveness and usefulness of these functions, specific situations reflecting common occurrences in a school setting are designed and implemented. Each situation is carefully chosen to represent a real-life event that could occur in a school environment, allowing for a demonstration of how the web application can be used to enhance the QOL of students and increase building efficiency during the operation period through Life Cycle Assessment (LCA).

In the subsequent sections, each situation is delved into in detail, explaining how they were employed to demonstrate the functionality of the web application. While the focus of this chapter is on the 'how' of demonstrating the web application's functionality, it is crucial to note that in this research questions and objectives guided the choice of situations and the testing process.

The situations assessed for our methodology include the following details:

A. Situation Description:

A situation is considered from the perspective of the students, who are the target users of this web application. In this situation, Student A, a 6-year-old, is about to start her first day of school in a new building and environment. To boost her confidence and comfort, she can experience a virtual tour in advance with her family through the school's web application. This tour is designed with a game-like interface, where the student follows a toy to reach the classroom, making the experience more engaging for young students.

Situation Selection: This specific situation was chosen based on sustainability goals and the importance of education quality and life improvement. The aim is to boost the confidence of young students in their environment, thereby enhancing their quality of life and study. This situation also demonstrates the advantages of 3D surveying through the building and the results of this research.

Situation Representation: In this situation, an animated movement through the model with a specific walkthrough map leading to a specific destination, which in this case is the classroom, is expected. The game-like interface and the toy guide are key elements in this representation.

Testing the Web Application: The animation is modeled in advance using BIM parts and the walkthrough for each destination is programmed. By using an embedded link, it is playable on the web app page. The test focused on the functionality of the game-like interface and the effectiveness of the toy guide in helping the student navigate the building.

B. Situation Description:

In this situation, Teacher B, who has a class on the second floor with thirteen students, encounters an issue where one of the windows in her classroom does not close properly. This causes heat loss and makes the room cold for her and her students. As the primary users of this room, they can report these problems through the school's web application. By opening the app and clicking the exact window in the Building Information Modeling (BIM) model of the school, she can submit it to expedite the process.

The Selection of This Situation: The selection of this situation was made specifically to illustrate the role of direct users in the upkeep of their building. The responsibility does not solely rest with the maintenance team. The acceleration of this process is achieved by the inclusion of regular users. This is in alignment with sustainability objectives and demonstrates the possibility of a more efficient operational period for the building throughout its life cycle.

What It Represents: This situation represents a real-life situation where the users of a building can contribute to its maintenance and efficiency. It shows how a web application, specifically designed with user-friendly Graphical User Interfaces (GUIs), can facilitate this process.

How It Was Used to Test the Web Application: This situation is used to evaluate the functionality and user-friendliness of the web application. The focus is on how easily the users can navigate the BIM model of the school, identify the problem area, and report the issue.

Testing Process Description: The testing process involves simulating the situation and having users interact with the web application. Observations are made on how they navigated the BIM model, identified the problem window, and reported the issue. Feedback is also collected from the users about their experience using the web application.

C. Situation Description:

In this situation, Rector C and Design Engineer D have decided to implement some modifications in the school, such as the garden's redesign and a change in the wall colors. To engage students in the building's management, a questionnaire is conducted, presenting distinct options based on student preferences. An exemplar question is: "The painting of your classroom is impending, which color would you prefer? Would you like any images? Please illustrate it in the box below."

The Reason for Choosing This Situation: The selection of this situation was made to evaluate Bubble's capability to support research objectives. It presents a challenging test as it involves determining whether Bubble is beneficial and operates efficiently enough for the asked requirements. It also considers the role of first-grade parents in assisting students to access or comprehend the instructions.

What It Symbolizes: This situation symbolizes a real-world Situation where the primary users of the school, the students, are empowered in the building's management. By opting for drawing over typing, it aims to obtain their direct response to the question.

How It Was Used to Test the Web Application: This situation is used to evaluate the functionality and user-friendliness of the web application. The focus is on how easily the users can navigate the questionnaire, understand the questions, and provide their input.

Testing Process Description: The testing process involves simulating the situation and having users interact with the web application. Observations are made on how they navigated the questionnaire, understood the questions, and provided their input. Feedback is also collected from the users about their experience using the web application.

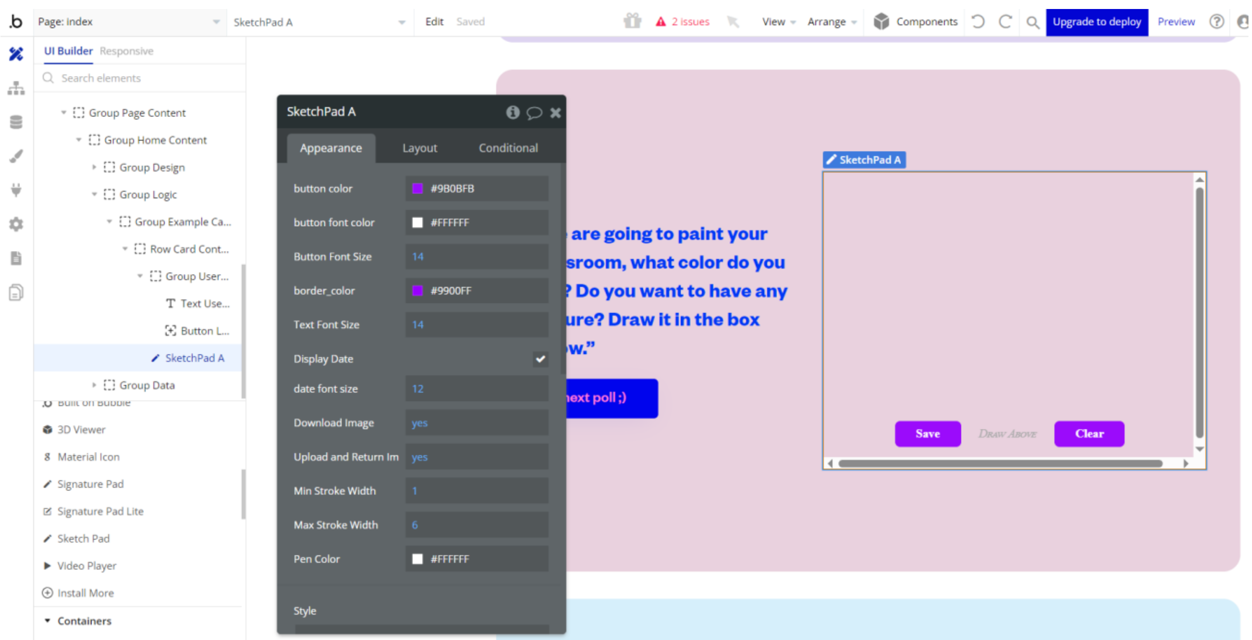


Figure 16 The tools view considered for the target

Summary

The Methodology Chapter: A detailed account of the design and methods employed to develop a user-focused web application for a primary school in Crodo, Italy is provided in the methodology chapter of the research. The research design was tailored to cater to the specific needs of the end-users and the functions of the school building.

The Case Study: An in-depth analysis of the school, its students, and its location participated in the case study. The unique characteristics of the school were taken into consideration to ensure the effectiveness of the application in its intended setting.

Web Application Characteristics: The characteristics of the web application were determined based on the functions of the buildings and its users. The application was designed with the aim of contributing to several sustainability goals and enhancing user experience.

Interoperability Analysis: The overlap between the ICT world and the BIM world was explored in the interoperability analysis. Various strategies were employed to ensure the effective integration of the BIM outputs into the ICT world.

Web Application Design Process: The web application design process involved the selection of the appropriate development methodology. The design process was centered around navigating through the building using an embedded model, which aided in familiarizing students with the school building and providing a platform for them to comment or report on building issues.

Efficiency Testing: The efficiency of the web application was tested through different situations that reflect common scenarios in a school setting. Feedback was collected from the users about their experience using the web application.

Limitations

Expensive Licenses: The testing of various tools and formats required for this research often involved expensive licenses. This could potentially limit the accessibility and replicability of the study.

Technical Complexity: Some of the complete tools used in the study were complex and time-consuming to use. This could pose a challenge for researchers without an elevated level of technical expertise.

Hardware Requirements: Certain tools require powerful PCs, like those used for gaming and animation software. This hardware requirement could be a barrier for researchers with limited resources.

Expertise Requirement: Both the web development and the 3D experiences part of the methodology through animation or gaming instead of directly using the output from the BIM model require specific expertise. This could limit the number of researchers who can effectively use this methodology.

These limitations highlight the challenges encountered during the research and provide valuable insights for future studies in this area. Despite these limitations, the methodology provides a comprehensive approach to developing a user-focused web application for educational institutions. Future research could explore ways to overcome these limitations and further improve the methodology.

Results

Review

The process of achieving the desired outcomes in this research was complex and multifaceted. As outlined in the methodology chapter, each step was rigorously tested using various tools and conditions.

The initial phase involved identifying an appropriate format for the 3D model that would be compatible with a web application. This was followed by the design of the web environment, a process that required careful consideration and planning.

In this Chapter: The evaluation of the results of these endeavors will be conducted. The quality and functionality of the outcomes will be scrutinized, and an assessment will be made to determine if they align with expectations and cater to the needs of target users.

The subsequent sections will offer an in-depth analysis of these results. The effectiveness of the web application in fostering sustainability, enhancing user experience, and enabling interaction between individuals and their buildings will be evaluated.

This chapter serves as a critical evaluation of the research process, highlighting the challenges encountered and the insights gained. It reflects research commitment to enhancing the interaction between users and their buildings, contributing to sustainability goals, and improving user experience.

The results of the research will be unfolded step by step in the following sections.

Interoperability Findings evaluation

The process of achieving interoperability involved assessing all conditions using various plugins and exporting through different tools. The results were intriguing, with the majority of them consisting of a package of materials, information, text, and other attached files. For instance, the object came with mtl, the gltf with bin, and some with texture jpeg and note.

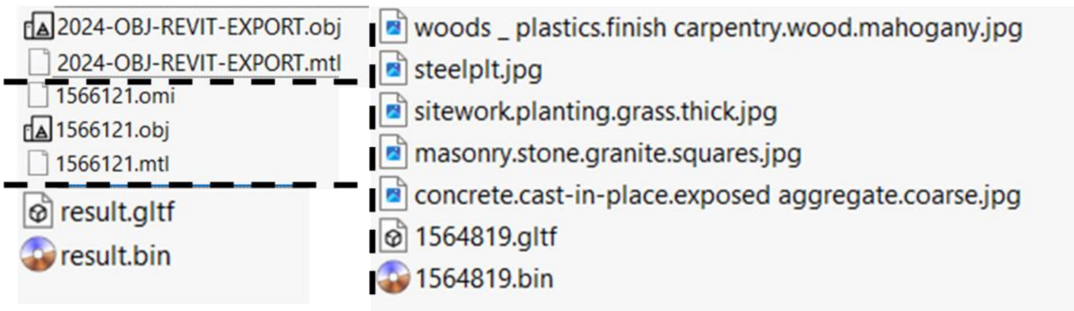


Figure 17 The example of export file items

Name	Size
2024-GLTF-CONVERT3D-IFC-EXPORT.zip	2,278 KB
2024-OBJ-REVIT-EXPORT.rar	21,008 KB
2024-OBJ-FILESTAR-IFC-EXPORT.obj	12,127 KB
2024-GLTF-FILESTAR-IFC-EXPORT.gltf	2,823 KB
2024-GLB-FILESTAR-IFC-EXPORT.glb	3,447 KB
2022-GLB-FILESTAR-IFC-EXPORT.glb	3,447 KB
2022-GLTF-FILESTAR-IFC-EXPORT.gltf	2,823 KB
2022-OBJ-FILESTAR-IFC-EXPORT.obj	12,128 KB
2024-GLB-ImageToStl-IFC-EXPORT.glb	12,412 KB
2024-OBJ-ImageToStl-IFC-EXPORT.zip	2,277 KB
2022-OBJ-ImageToStl-IFC-EXPORT.zip	2,277 KB
2022-GLB-ImageToStl-IFC-EXPORT.glb	12,410 KB
2024-OBJ-CONVERT3D-IFC-EXPORT.zip	9,300 KB
2024-GLB-CONVERT3D-IFC-EXPORT.glb	9,731 KB
2022-GLB-CONVERT3D-IFC-EXPORT.glb	9,731 KB
2022-GLTF-CONVERT3D-IFC-EXPORT.zip	2,278 KB
2022-OBJ-CONVERT3D-IFC-EXPORT.zip	9,306 KB
2024-OBJ-MODELLO-IFC-EXPORT.zip	13,325 KB
2024-GLTF-MODELLO-IFC-EXPORT.zip	3,153 KB
2024-OBJ-MODELLO-RVT-EXPORT.zip	1,599 KB
2024-GLTF-MODELLO-RVT-EXPORT.zip	389 KB
2022-OBJ-MODELLO-IFC-EXPORT.zip	13,321 KB
2022-GLTF-MODELLO-IFC-EXPORT.zip	3,179 KB
2022-GLTF-MODELLO-RVT-EXPORT.zip	447 KB
2022-OBJ-MODELLO-RVT-EXPORT.zip	1,642 KB

Figure 18 The frame of result files with their size

An interesting observation is that if it ran these out of their folder, the 3D model was not readable or was completely solid. Another notable point was the size difference between different file formats. It was understood that obj is a larger file than glb and gltf.

In the Evaluation of Final Results: Different format indicators were taken into consideration:

Pivot Points: The 3D file was played and rotated, revealing that at times the pivot point is not central and the X, Y, Z coordinates do not align with reality, resulting in incorrect rotation.

Material: Initially, material was the only indicator considered. However, upon reviewing more results, it was understood that the elements of material color and texture should be considered separately. There are instances where only color is present, without texture, or vice versa.

Geometry: This refers to the physical attributes of the building, such as the angles or arcs of the building components.

Topography: In certain tests, the topography was not visible. The reason for this remains unclear.

Building Information: Some formats can store the building information set in the BIM engine. While it does not function as it does in the BIM viewer, if played in the BIM or IFC reader, their existence can be noted. An example is the direct export obj format from Revit 2024, which has the largest size among all results.

Shadow: It was found interesting that the building can display the shadow from fixed point light sources, and the shadow movement can be easily understood by rotating the model.

To populate the table comparing test results, the following were considered: R=RIGHT, W=WRONG, M=MODERATE, _=NOT EXIST.

The results are presented in a table, following the same logical flow as in the methodology. The files are categorized based on their origin - whether they were generated from a plugin or exported from other tools. Each category is represented with two tables, along with an evaluation of the indicators. In the second table, an attempt has been made to illustrate the 3D view of points for each file. This approach allows for a comprehensive and organized presentation of all findings.

It is noteworthy that after reviewing all the results for the objectives, the obj format was selected. This decision was based on the fact that the obj format received the highest evaluation across all indicators. This underscores the effectiveness of the obj format in meeting the research goals. It is obvious that for different goals other results are acceptable as well. But in this study, the outcomes used are EMBED from modelo and obj from IFC convert in the convers3d tool.

The highlighted block in each table demonstrates the chosen and used format for the different purposes in web applications.

Plug-in	Tool	Action	Format	Pivot point	Color	Texture	Geometry	Topography	Information	Shadow
Revit 2022	Enscape	Export	URL	R	M	M	R	R	R	R
	Modelo	Export	URL	R	M	M	M	R	R	R
			Embed	R	M	M	M	R	_	R
		Convert	obj	R	M	M	M	R	_	R
			gltf	R	M	M	M	R	_	R
Revit 2024	Enscape	Export	URL	R	M	M	R	R	R	R
	Modelo	Export	URL	R	W	W	M	R	R	R
			Embed	R	W	W	M	R	_	R
		Convert	obj	W	W	W	M	R	_	R
			gltf	R	W	W	M	R	_	R

Figure 19 The table summary of Interoperability format Findings evaluation FROM plugin

Plug-in	Tool	Action	Format	3D View
Revit 2022	Enscape	Export	URL	
	Modelo	Export	URL	
			Embed	
		Convert	obj	
			gltf	

...table continues next page...

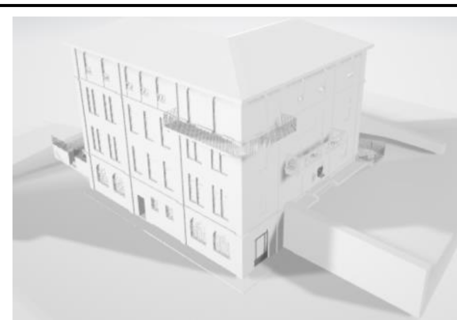
Plug-in	Tool	Action	Format	3D View
Revit 2024	Enscape	Export	URL	
	Modelo	Export	URL	
			Embed	
		Convert	obj	
			gltf	

Figure 20 The table 3D View of Interoperability format Findings evaluation FROM plugin

Export		Tool	Action	Format	Pivot point	Color	`Texture	Geometry	Topography	Information	Shadow
Revit 2022	RVT	Modelo	Export	URL	R	M	M	W	R	R	R
				Embed	R	M	M	W	R	_	R
			Convert	obj	W	M	M	W	R	_	R
				gltf	R	M	M	W	R	_	R
	IFC	Modelo	Export	URL	R	M	_	W	W	R	R
				Embed	R	M	_	W	W	_	R
			Convert	obj	W	M	_	W	W	_	R
				gltf	R	M	_	W	W	_	R
		Imagetostl	Convert	obj	R	W	W	W	W	_	M
				glb	W	W	W	W	W	_	M
		Convert3d	Convert	obj	R	R	_	R	R	_	R
				gltf	R	R	_	R	R	_	R
				glb	R	R	_	R	R	_	R
		Filestar	Convert	obj	R	W	W	W	W	_	M
				gltf	_	_	_	_	_	_	_
				glb	R	M	_	W	M	_	R

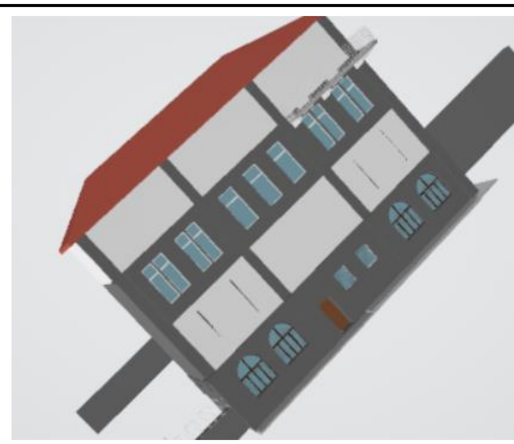
...table continues next page...

Export		Tool	Action	Format	Pivot point	Color	`Texture	Geometry	Topography	Information	Shadow
Revit 2024	RVT	Modelo	Export	URL	R	R	–	W	R	R	R
				Embed	R	R	–	W	R	–	R
			Convert	obj	W	R	–	W	R	–	R
				gltf	R	M	–	W	R	–	R
	IFC	Modelo	Export	URL	R	W	–	W	W	R	R
				Embed	R	W	–	W	W	–	R
			Convert	obj	W	W	–	W	W	–	R
				gltf	R	W	–	W	W	–	R
		Imagetostl	Convert	obj	R	W	W	W	W	–	M
				glb	W	W	W	W	W	–	M
		Convert3d	Convert	obj	R	R	–	R	R	–	R
				gltf	R	R	–	R	R	–	R
				glb	R	R	–	R	R	–	R
		Filestar	Convert	obj	R	W	W	W	W	–	M
				gltf	–	–	–	–	–	–	–
				glb	R	M	–	W	M	–	R
	OBJ	Revit	Export	obj	W	M	–	R	R	R	R

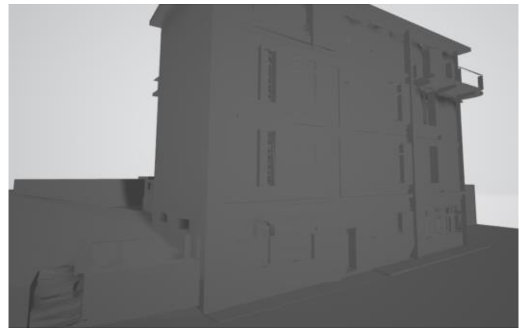
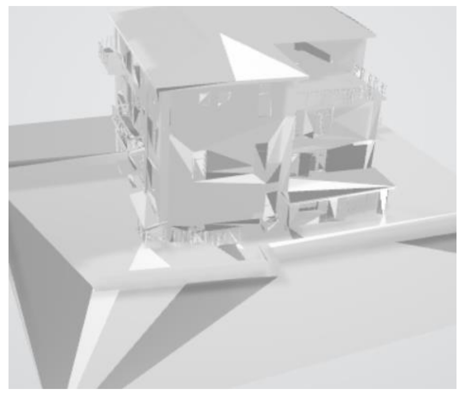
Figure 21 The table summary of Interoperability format Findings evaluation FROM export

Export		Tool	Action	Format	3D View
Revit 2022	RVT	Modelo	Export	URL	
				Embed	
			Convert	obj	
				gltf	

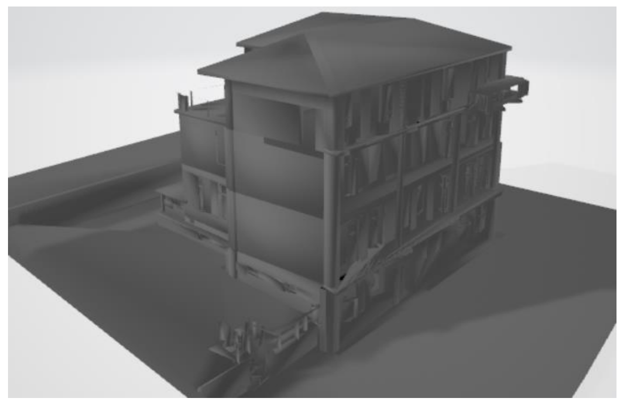
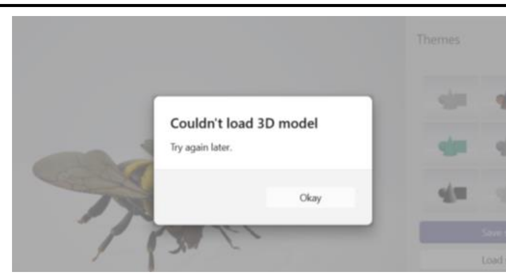
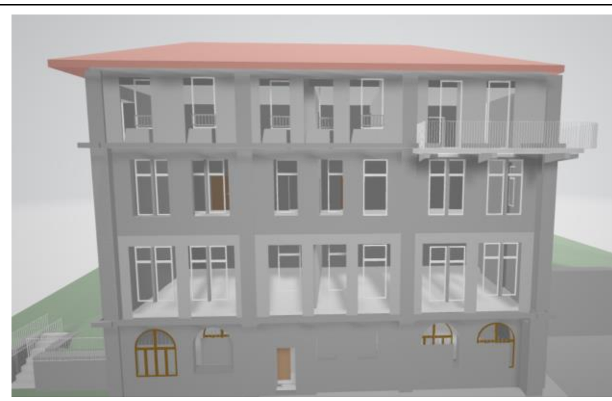
…table continues next page…

Export		Tool	Action	Format	3D View
REVIT 2022	IFC	Modelo	Export	URL	
				Embed	
			Convert	obj	
				gltf	

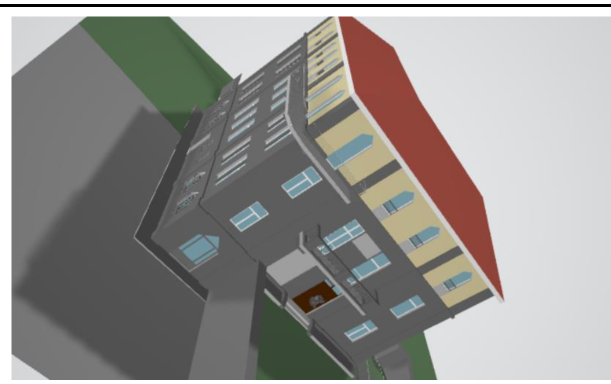
…table continues next page…

Export		Tool	Action	Format	3D View
Revit 2022	IFC	Imagetostl	Convert	obj	
				glb	
		Convert3d	Convert	obj	
				gltf	

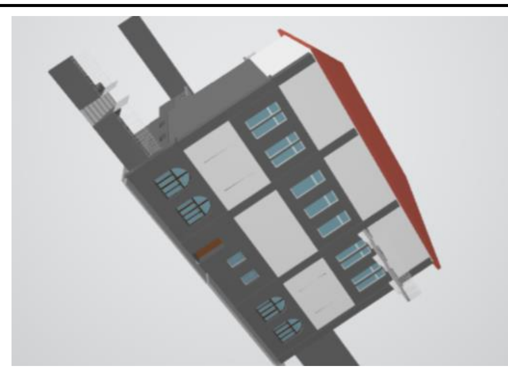
...table continues next page...

<table>
<tr><th colspan="2">Export</th><th>Tool</th><th>Action</th><th>Format</th><th>3D View</th></tr>
<tr><td rowspan="4">Revit 2022</td><td rowspan="4">IFC</td><td>Convert3d</td><td>Convert</td><td>glb</td><td></td></tr>
<tr><td rowspan="3">Filestar</td><td rowspan="3">Convert</td><td>obj</td><td></td></tr>
<tr><td>gltf</td><td>
</td></tr>
<tr><td>glb</td><td></td></tr>
</table>

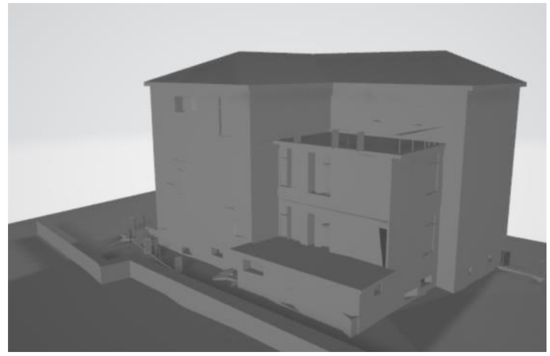
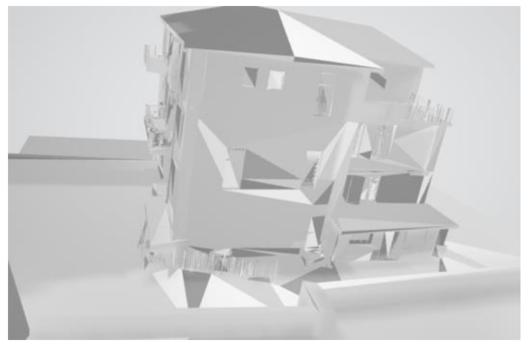
…table continues next page…

Export		Tool	Action	Format	3D View
Revit 2024	RVT	Modelo	Export	URL	
				Embed	
			Convert	obj	
				gltf	

...table continues next page...

Export		Tool	Action	Format	3D View
REVIT2024	IFC	Modelo	Export	URL	
				Embed	
			Convert	obj	
				gltf	

...table continues next page...

Export		Tool	Action	Format	3D View
Revit 2024	IFC	Imagetostl	Convert	obj	
				glb	
		Convert3d	Convert	obj	
				gltf	

...table continues next page...

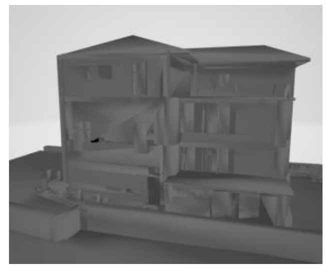
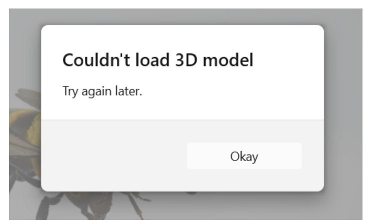
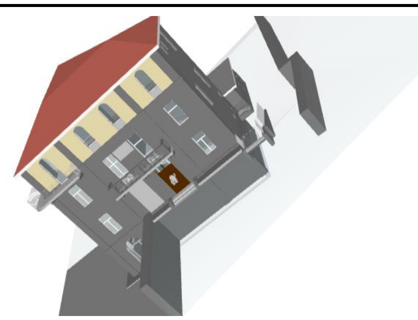
Export		Tool	Action	Format	3D View
Revit 2024	IFC	Convert3d	Convert	glb	
		Filestar	Convert	obj	
				gltf	
				glb	
	obj	Revit 2024	Export	obj	

Figure 22 The table 3D View of Interoperability format Findings evaluation FROM export

Web Application Look

This work has resulted in a web application that displays a 3D model of the school building. While the primary expertise lies in building engineering, the application was developed with an emphasis on user-friendliness. The 3D model is detailed, aiming to enhance the user experience.

It is worth mentioning that the involvement of professional web developers could potentially improve the results. Their proficiency in web development could contribute to the design, functionality, and user experience of the application.

The subsequent section of this chapter will present various results that support the efficiency of the purpose-built web application. These results aim to demonstrate the effectiveness of this approach and its advantages for the school community. The application incorporates features that encourage sustainability and aim to enhance the quality of life for end-users.

In summary, the web application serves the school community as intended. There is always room for improvement, and the current achievements indicate the potential for further development. This underscores the significance of interdisciplinary collaboration and purpose-built design in the creation of effective web applications.

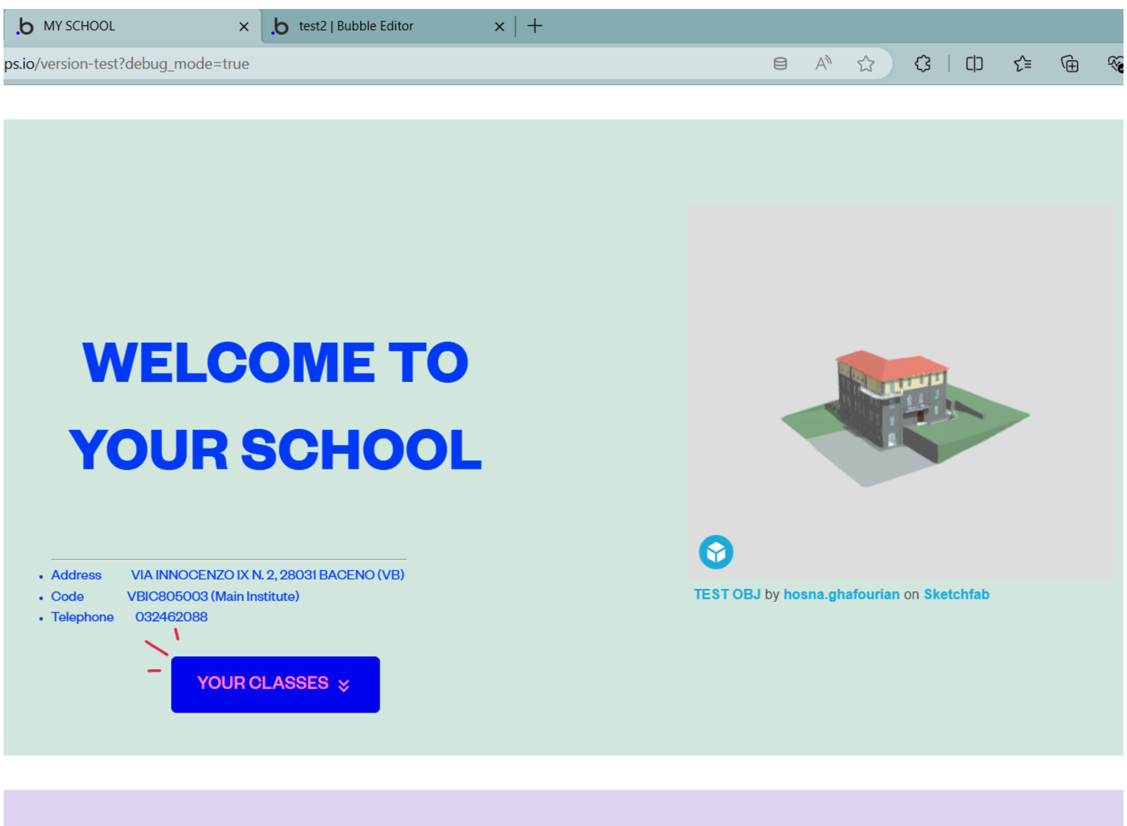


Figure 23 The home page of web application of school

Hypothesis Outcomes

A:

Situation Description - Virtual Tour for New Students: In this Situation, a 6-year-old student, Student A, is about to start her first day of school in a new building. To boost her confidence, she and her family use the school's web application to take a virtual tour of the school building in advance.

Figure 24 walkthrough the building example for specific destination

Implementation of Additional Feature is the integration of a game-like interface as an added feature of the web application presented a considerable challenge. This feature, aimed at engaging users who are children in this building, required supplementary tools and expertise in areas such as game design. Nevertheless, an attempt was made to evaluate the concept with the minimal tools available.

The toy family in Revit software was utilized throughout the entire route of each destination. For this feature of the web application, the embedded file from Modelo platforms was employed. The workflow involved the creation of a new import of the building for each destination, the demonstration of the pathway, and the setting of the walkthrough. Following this, the link of the embedded file was shared on the specific page of the web application, in this instance, Class 1.

Users can then interact with it through the screen and experience it. Unlike a video, this offers a real experience where the starting point can be chosen by the user, rotation can occur during the walk, and the surroundings can be observed. This leads to a dynamic experience.

B:

Situation Description - Reporting Building Issues: In the second Situation, Teacher B, who conducts a class on the second floor, encounters a window in her classroom that does not close properly. Utilizing the school's web application, she and her students report the problem, which aids in expediting the repair process.

One of the primary objectives of BIM is to monitor all components of a building at different stages of its life cycle for maintenance, management, and other aspects. Autodesk's APS Autodesk platform services are a potent platform for this purpose, offering various tools that work on building information and demonstrate them for similar or different targets.

One such tool, which is easy to use and has a user-friendly interface, is Modelo. In this research, it is attempted to amalgamate these professional tools with a user-friendly interface for public use for each building and its specific users.

A critical point to note is that the dashboard of reported comments is not stored in the web application cloud. Instead, it is cached and stored in Modelo's cloud, a place where only the building expert and maintenance personnel have access to validate and control each report.

Thanks to Modelo URL and the web application's features, it has a combined result that utilizes these features of the BIM methodology for the building. This provides a solution for these kinds of Situations.

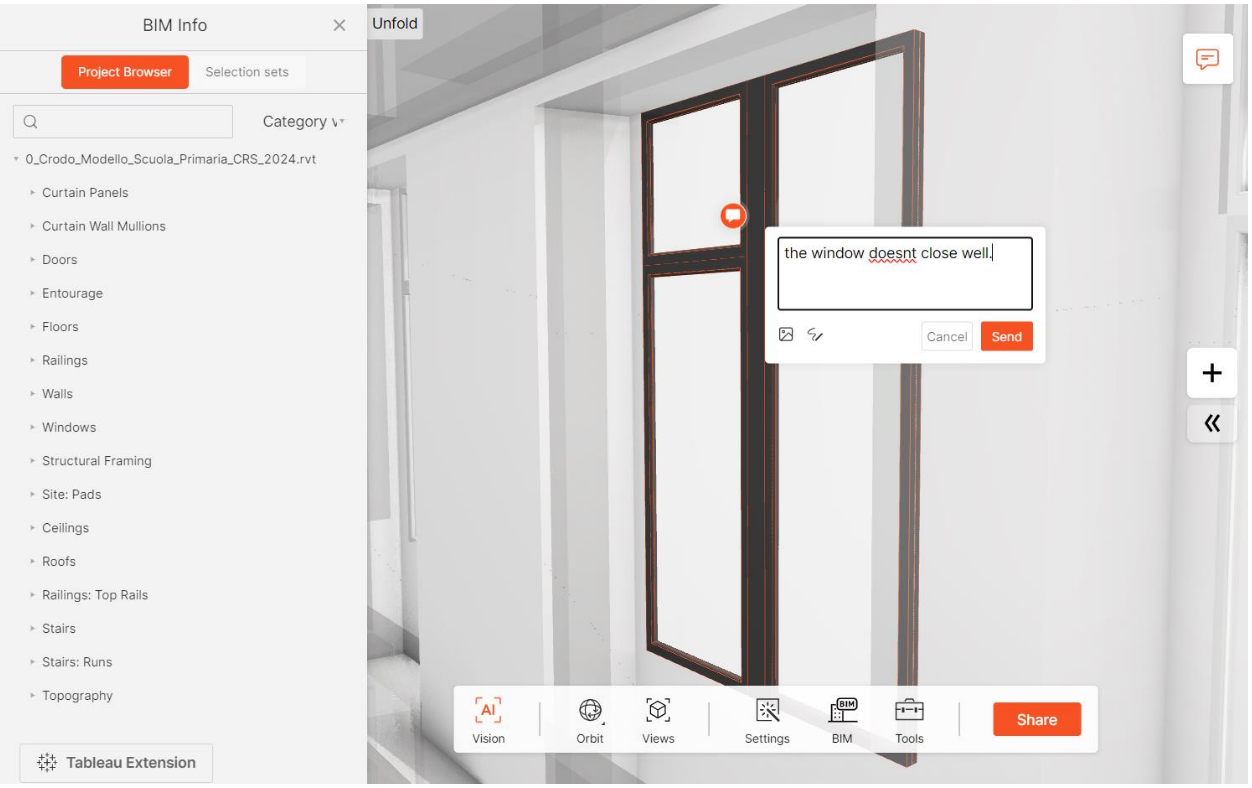


Figure 25 The example of Commenting on building components

Figure 26 The dashboard page in Modelo to store all received reports

C:

Situation Description - Involving Students in Building Management: In the final Situation, Rector C and Design Engineer D decide to make some changes in the school, such as redesigning the garden and changing the color of the walls. They run a questionnaire through the school's web application to involve students in the decision-making process.

The Central Role in this Situation is the web application plays the leading role in this Situation. Three different methods for designing the web app were introduced: Zero-code (No-Code) Platforms, Low-Code Platforms, and Traditional Coding Platforms. Each of these methods provides different solutions, features, and levels of customization for Situations with a focus on question-answering aims.

For this project, a no-code method using Bubble.io was chosen, with the request being adapted to the capabilities available on the platform. The platform was found to be well-suited to users' needs, offering the ability to create a questionnaire, collect answers, and store them for later analysis.

In this specific situation, a challenging situation was chosen where the users are students who may not yet have strong reading or writing skills. A method for their participation was needed, so the question-and-answer box was designed to host drawings instead of typed responses or selected options. To answer the question about their preferred wall color for their classroom, they could select a paint color and then draw a picture they wanted, save it, and send it.

On the other side, all their drawings, along with the information, were submitted to a dashboard where it could be easily collected. It is important to note that the current version of the web application is for testing and has not been fully designed from a policy or login process perspective. However, the potential to design all the necessary processes certainly exists.

This Situation demonstrates the potential of no-code platforms like Bubble.io in engaging users in a meaningful and accessible way, even when those users are young students. It also highlights the importance of user-friendly design and the ability to adapt to the specific needs and capabilities of the user base.

It is notable that this test was not conducted by actual students at the school, but the main aim was to check the workflow of the processing function of the application. However, a new goal for future work could be to test all hypotheses on the real students at the school.

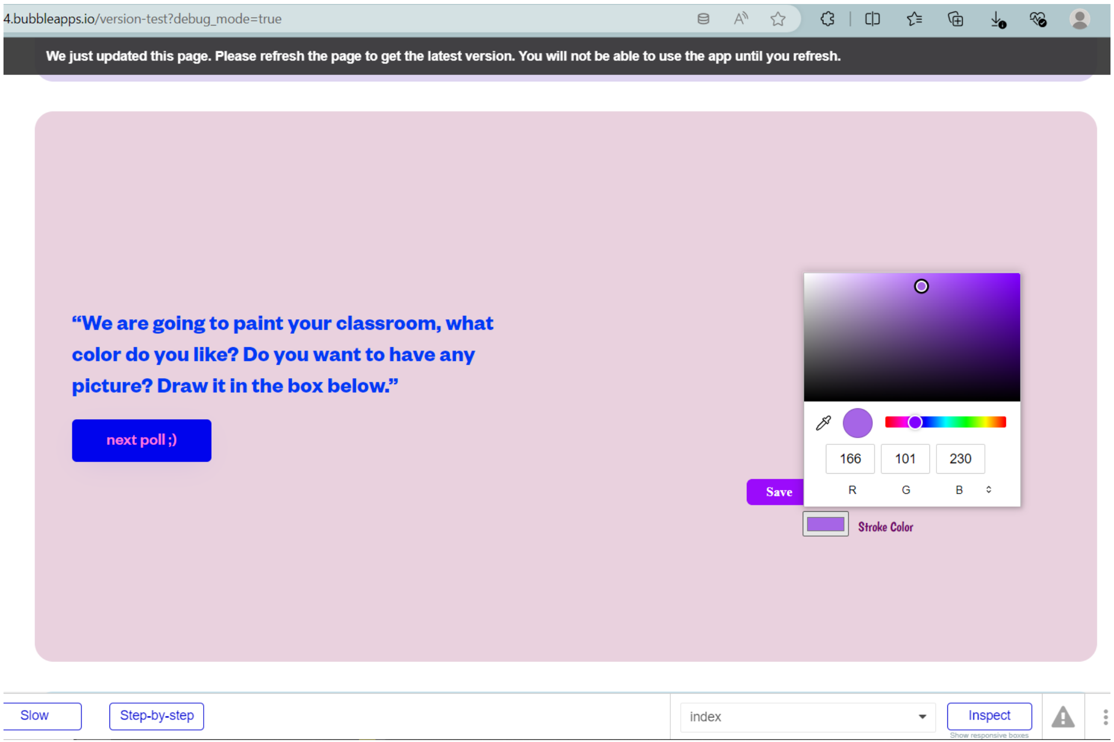


Figure 27 The web app page demonstrates the question and answering step1 choosing the color

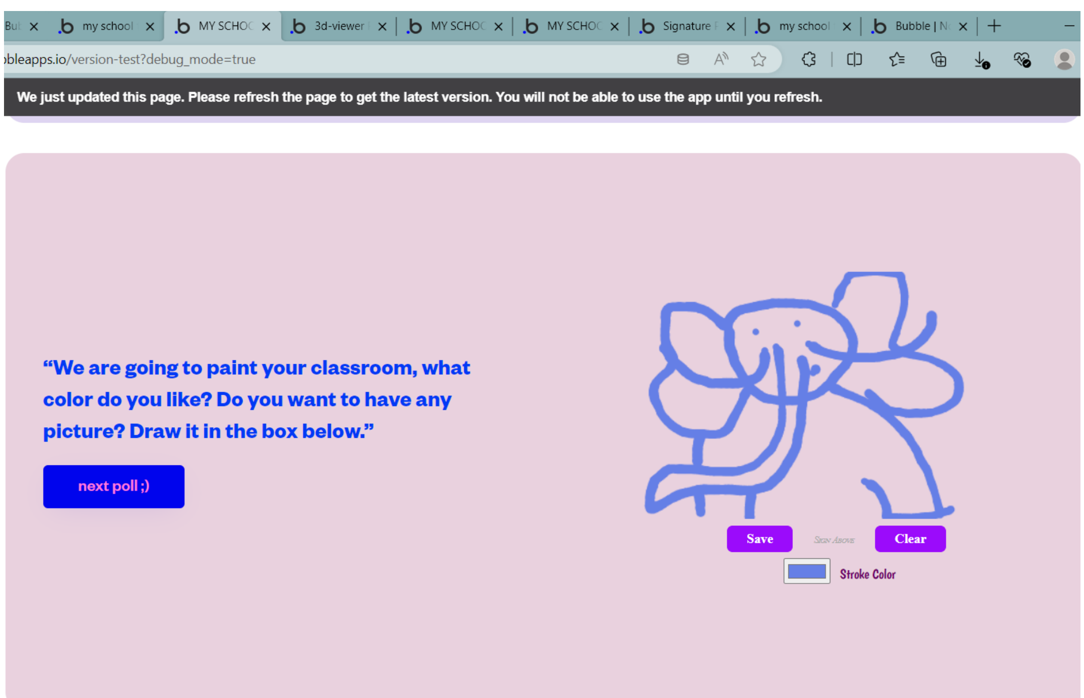


Figure 28 The web app page demonstrates the question and answering step2 painting the answer

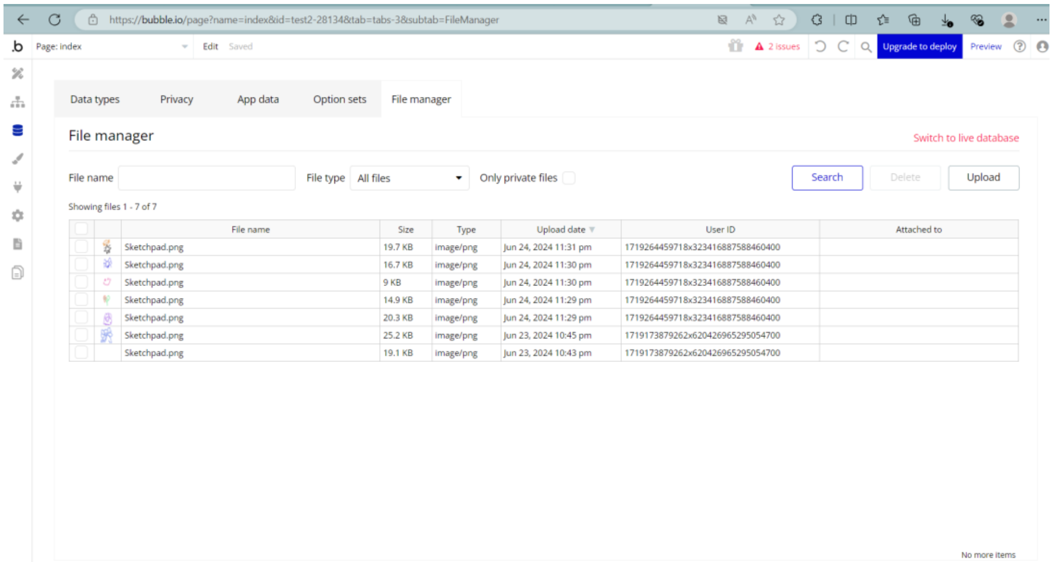


Figure 29 The web app page demonstrates the question and answering step3 the dashboard of all received answers

Figure 30 The web app page demonstrates the question and answering step4 collecting the answers

Wrapping Up

The process of achieving interoperability and creating a user-friendly web application was challenging but successful. The results were intriguing, with the majority of them consisting of a package of materials, information, text, and other attached files. The obj format was selected based on its highest evaluation across all indicators, underscoring its effectiveness in meeting research goals.

The result of this work is a user-friendly web application that successfully displays a 3D model of the school building. Despite the challenges, the web application was developed successfully and presents an intuitive and visually appealing interface. The 3D model is detailed and accurate, enhancing the user experience.

However, it is important to note that collaboration with professional web developers could undoubtedly enhance the results. Their expertise and experience in web development could bring significant improvements to the design, functionality, and user experience of the application.

Challenges

One of the significant challenges faced was the integration of a game-like interface as an added feature of the web application. This feature, intended to engage the young users of the building, necessitated supplementary tools and expertise in fields such as game design. Despite the complexity, an effort was made to evaluate the concept using the minimal tools at disposal.

Another challenge was associated with the management of user-generated content. The task of ensuring the privacy and security of the data, while making it accessible for validation and control, was complex. However, a solution that effectively balanced these requirements was devised.

In conclusion, despite the challenges encountered, the project was a success. The web application has met the expectations and serves as a valuable tool for the school community. These points highlight the potential for further improvement and the value of the current achievements. They underscore the importance of interdisciplinary collaboration and purpose-built design in creating effective web applications. The project serves as a valuable case study for future projects.

Discussion

Restatement of Research focus

The primary focus of this research was to address a significant gap in the field of sustainable building. Despite the growing use of Information and Communication Technology (ICT) in this field, most existing tools are designed for professionals, not the end-users of the buildings. This lack of user-focused ICT tools limits the potential for interaction between people and their buildings, which is a crucial aspect of achieving sustainability goals.

The research aimed to design a user-focused ICT tool that enhances the interaction between people and their buildings, particularly in the context of sustainability. The objectives were to identify the needs of end-users, design the ICT tool, integrate it with Building Information Modelling (BIM), create a user-friendly dashboard, assess the tool in a real-world setting, and evaluate the results.

The research questions focused on how ICT in a web application can be chosen and designed to improve interaction between end-users and their buildings, how the design of a web application can be tailored to the specific needs and characteristics of different end-users and different types of buildings, how this tailored design of the web application contributes to sustainability goals and sustainable building practices, and how interoperability between different software from different disciplines can be achieved for the web application.

The hypotheses proposed that the choice and design of ICT in a web application can significantly improve the interaction between end-users and their buildings, a web application designed with consideration to the specific needs and characteristics of different end-users and types of buildings can significantly enhance user participation and interaction, a tailored design of the web application contributes significantly to sustainability goals and sustainable building practices by enhancing user interaction and participation, and interoperability between different software can be achieved through specific format conversions and exports, enhancing the functionality and user-friendliness of the web application.

In conclusion, the focus of this research was to enhance the interaction between people and their buildings through a user-focused web application, contributing to improved user experience and increased sustainability. The research underscores the importance of user-focused design and interoperability in enhancing the functionality and user-friendliness of web applications. It also highlights the need for further research in this area to continue to improve and innovate in the field of sustainable building.

Summary of Key Findings

The research process involved achieving interoperability by evaluating all possible conditions using various plugins and exporting through different tools. The results were intriguing, with the majority of them consisting of a package of materials, information, text, and other attached files. For instance, the object came with mtl, the gltf with bin, and some with texture jpeg and note.

Interesting Observation is that if these were run outside of their folder, the 3D model was either not readable or was completely solid. Another point of note was the size difference between different file formats. It was understood that the obj file is larger than both the glb and gltf files.

Results Evaluation: Different format indicators such as pivot points, material, geometry, topography, building information, and shadow were considered to evaluate the final results. The obj format received the highest evaluation across all indicators, highlighting the effectiveness of the obj format in meeting the research goals.

The result of this work is a user-friendly web application that successfully displays a 3D model of the school building. The web application was developed successfully, and it presents an intuitive and visually appealing interface. The 3D model is detailed and accurate, enhancing the user experience.

Interpretation and Explanation of Results

The results of the research indicate that achieving interoperability in the context of a user-focused web application for sustainable buildings involves a complex process of testing and evaluation. The use of various plugins and exporting through different tools resulted in a variety of file formats, each with its own set of characteristics and challenges.

The finding that the obj format was larger than glb and gltf, but provided the most comprehensive package of materials, information, text, and other attached files, suggests that the obj format offers a balance between detail and usability that makes it particularly suited to this application.

The evaluation of the results using different format indicators provided valuable insights into the performance of the different file formats. The fact that the obj format received the highest evaluation across all indicators supports the decision to select this format for the web application.

The successful development of the web application, despite the primary expertise of the team being in building engineering, demonstrates the potential for interdisciplinary collaboration in the creation of user-focused ICT tools for sustainable buildings. The detailed and accurate 3D model enhances the user experience, promoting interaction between people and their buildings and contributing to sustainability goals.

The results of the research underscore the importance of user-focused design and interoperability in enhancing the functionality and user-friendliness of web applications. They also highlight the potential for further improvement and the value of the current achievements. The research provides a valuable case study for future projects in the field of sustainable building.

Comparison with Previous Research

Previous research in the field of Architecture, Engineering, and Construction (AEC) has primarily focused on the use of Information and Communication Technology (ICT) tools such as Building Information Modelling (BIM) and web applications for professionals in the industry. These studies have explored the potential of these tools in enhancing building design and management, promoting sustainable practices, and achieving sustainable building goals.

However, a significant gap identified in these studies is the lack of user-focused ICT tools that promote active participation of end-users in their building's management and sustainability. This is where this thesis makes a substantial contribution.

In this thesis, this gap is addressed by developing a user-focused web application designed specifically for end-users, not just experts or stakeholders. By considering the specific needs and characteristics of different end-users and types of buildings, this research has led to the creation of a web application that enhances user participation and interaction, improves user experience, and contributes to sustainability goals.

In comparison to previous research, this thesis stands out by emphasizing the role of end-users in the management of their buildings. This user-centric approach, combined with the integration of advanced ICT tools, has the potential to revolutionize the way users interact with their buildings and contribute to sustainability goals in the AEC industry. This thesis underscores the importance of user-focused design and interoperability in enhancing the functionality and user-friendliness of web applications, making a significant contribution to the field.

Consideration of the Research Methods

The research methodology employed in this study was comprehensive and tailored to the specific needs of the end-users and the functions of the buildings. It involved an in-depth analysis of the case study, integration with Building Information Modelling (BIM) tools, web application design, and efficiency evaluation. The methodology provided an integrated approach to understanding how a user-focused web application can enhance interaction between people and their buildings, contribute to sustainability goals, and improve user experience

Implications of the Research

The findings of this research have far-reaching implications. They demonstrate that a user-focused web application can significantly enhance the interaction between people and their buildings, leading to improved user experience and increased sustainability. The research underscores the importance of user-focused design and interoperability in enhancing the functionality and user-friendliness of web applications, making a significant contribution to the field of sustainable buildings.

Suggestions for Future Research

From a web developer's perspective, future work could focus on enhancing the interoperability between the web application and Building Information Modelling (BIM) tools. This could involve exploring new methods or technologies to streamline the integration process and improve the functionality of the web application.

There is also potential for collaboration with other industries, such as animation and gaming, to improve the graphical user interface and increase user-friendliness. Incorporating elements of game design, for example, could make the web application more engaging for young users and encourage their active participation.

In terms of the specific web application designed for this primary school, future research could focus on iterative design improvements based on user feedback and evolving needs. This could involve regular usability testing and updates to ensure the web application continues to meet the needs of its users and the goals of the school.

For researchers in the field of Architecture, Engineering, and Construction (AEC), it would be beneficial to apply this approach to other case studies. Given that the main considerations of this project are the function of the building and the features of the users, it would be interesting to see how this approach could be adapted for distinct types of buildings and user groups.

There are also different tools being developed or currently under consideration in the field that could be combined with this approach. For instance, using Power BI tools to enhance the database coming from the building and users and their interaction with the building could provide valuable insights for building management and sustainability.

Finally, while the use of Virtual Reality (VR) or Augmented Reality (AR) tools was not considered for this case study due to age restrictions, these technologies offer exciting possibilities for future research. They could provide immersive and interactive experiences that further enhance user interaction with their buildings. However, ethical considerations, such as age restrictions, should always be considered when exploring these technologies.

Conclusion

This research aimed to address a significant gap in the field of sustainability in building by developing a user-focused web application designed to enhance the interaction between people and their buildings, particularly in the context of increase the sustainability. The research was grounded in the belief that technology and tools can significantly enhance the industry's ability to achieve sustainable development goals.

The methodology employed in this research was comprehensive and tailored to the specific needs of the end-users and the functions of the buildings. It involved an in-depth analysis of the case study, integration with Building Information Modelling (BIM) tools, web application design, and efficiency evaluation.

The findings of this research have far-reaching implications. They demonstrate that a user-focused web application can significantly enhance the interaction between people and their buildings, leading to improved user experience and increased sustainability. The research underscores the importance of user-focused design and interoperability in enhancing the functionality and user-friendliness of web applications, making a significant contribution to the field of sustainable buildings and sustainability.

The research also opens several avenues for future research in the field of sustainable buildings and sustainability. Future research could focus on exploring other user groups, investigating other ICT tools, expanding the case studies, conducting longitudinal studies, and integrating the web application with other systems.

In conclusion, this research has made significant strides in understanding how a user-focused web application can enhance the interaction between people and their buildings, contribute to sustainability goals, and improve user experience. The findings could have significant implications for the design of web applications in the context of sustainable buildings. The research underscores the importance of user-focused design and interoperability in enhancing the functionality and user-friendliness of web applications. It also highlights the need for further research in this area to continue to improve and innovate in the field of sustainability.

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