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BIM-DRIVEN COMMUNICATION OF DESIGN FOR RESIDENTIAL BUILDING PROJECTS: ENHANCING COST TRANSPARENCY AND BUYER ENGAGEMENT IN STAGED INVESTMENT MODELS

BIM-PODPRTA KOMUNIKACIJA PROJEKTNE ZASNOVE PRI STANOVANJSKIH GRADBENIH PROJEKTIH: IZBOLJŠANJE PREGLEDNOSTI STROŠKOV IN VKLJUČENOSTI KUPCEV V FAZNIH NALOŽBENIH MODELIH.

BIM A+ European Master in Building Information Modelling

Master thesis No.: 004:336.532.1:69(043.2)

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Ljubljana, 2025

ERRATA

Page	Line	Error	Correction

BIBLIOGRAFSKO – DOKUMENTACIJSKA STRAN IN IZVLEČEK

UDK: 004:336.532.1:69(043.2)

Avtor: Manzurul Haque

Mentor: Doc. dr. Tomo Cerovšek

Naslov: BIM-podprta komunikacija projektne zasnove pri stanovanjskih gradbenih projektih: izboljšanje preglednosti stroškov in vključenosti kupcev v faznih naložbenih modelih.

Tip dokumenta: magistrsko delo

Obseg in oprema: 87 str. , 42 sl.

Ključne besede: BIM, sprotni stroškovni odziv, stanovanjska gradnja, stopenjski naložbeni modeli, preglednost stroškov, vključenost kupcev, 5D BIM, klasifikacijski sistem

Izvleček:

Magistrsko delo obravnava vlogo informacijskega modeliranja gradenj (BIM) pri izboljšanju komunikacije s kupci v stanovanjskih projektih, ki temeljijo na faznih investicijskih modelih. Pri teh modelih sta zaupanje in transparentnost plačil odvisna od jasnega razumevanja stroškov in posledic projektnih odločitev. Kljub obstoju BIM-platform ostajajo te za laične uporabnike prezapletene, zato se kupci še vedno zanašajo na tradicionalne materiale, kot so risbe in vizualizacije. Glavni raziskovalni problem je odsotnost sistema, ki bi kupcem omogočal interaktivno raziskovanje možnosti, takojšen vpogled v stroškovne posledice in dinamično povezavo izbir z načrtom plačil.

Za rešitev tega problema smo razvili in preizkusili prototip na primeru stanovanjske enote, izolirane iz večjega objekta (G+4), pri čemer sta bili kot testna elementa uporabljeni kuhinjska predelna stena in talne obloge. Prototip, ki temelji na podatkih iz BIM-modela (količine, klasifikacijske kode) in 5D-popisa stroškov, omogoča kupcem, da v spletnem vmesniku (format GLTF) spreminjajo izbrane arhitekturne elemente, medtem ko konstrukcijski elementi ostajajo nespremenjeni. Vsaka sprememba sproži samodejni preračun stroškov v realnem času. Spremembe se zabeležijo v strukturiran izvoz (datoteka Excel), ki omogoča posodobitev v skupnem podatkovnem okolju (CDE) in posledično prilagoditev obrokov v faznem plačilnem modelu.

Kljub tehničnim omejitvam, kot sta nestabilnost delovanja in odsotnost regeneracije IFC-modela, je prototip uspešno dokazal, da je mogoče vzpostaviti delujoč koncept. Potrdil je, da so posodobitve stroškov, temelječe na klasifikacijskem sistemu, izvedljive in jih je mogoče učinkovito povezati s faznimi plačilnimi modeli. S tem delo ponuja osnovo za izboljšanje transparentnosti stroškov, zmanjšanje sporov in krepitev zaupanja v stanovanjski gradnji.

BIBLIOGRAPHIC– DOKUMENTALISTIC INFORMATION AND ABSTRACT

UDC: 004:336.532.1:69(043.2)

Author: Manzurul Haque

Supervisor: Assist. Prof. Tomo Cerovšek, Ph.D.

Title: BIM-driven communication of design for residential building projects: enhancing cost transparency and buyer engagement in staged investment models

Document type: Master thesis

Scope and tools: 87 p, 42 fig.

Keywords: BIM, Real time cost feedback, Residential construction, Staged investment models, Cost transparency, Buyer engagement, 5D BIM, Classification system

Abstract:

This thesis examines how Building Information Modelling (BIM) can improve communication with homebuyers in residential projects. It focuses on staged investment models, where instalment payments and trust rely on cost transparency & clear information about design choices and costs. Traditionally buyers rely on drawings, brochures and visualisations, while BIM platforms remain complex for nontechnical users. A gap persists: no system lets buyers view options, see cost impact, and connect choices to payment schedules dynamically.

To address this gap, a prototype was developed and tested. A flat was extracted from a G+4 building, with a kitchen partition wall and floor finishes as tests. The system imported data from the BIM model, including quantities, classification codes and unit prices from a 5D cost sheet, establishing a baseline for cost. The model gets converted to GLTF so buyers could change architectural elements while structural remains locked. Each change triggered quantity recalculation applied the unit rate and updated the total price on screen. The changes were saved in an Excel file and uploaded to the Common Data Environment, enabling updates of staged instalments instantly.

The prototype was limited to one unit, faced stability issues and lacked IFC regeneration. Even so, it showed that classification-based cost updates are feasible and can be tied to staged payment models, offering a proof of concept for cost transparency, fewer disputes and trust in residential construction.

ACKNOWLEDGEMENTS

First and foremost, I express my deepest gratitude to Professor Tomo Cerovšek, whose guidance, encouragement and ability to inspire out-of-the-box thinking shaped this work and broadened my perspective. His advice to never confine myself to tools or closed ideas has been invaluable throughout this journey. I am equally thankful to all the professors and assistants of the programme, whose collective support and distinct direction have helped me find my path in the field of digital construction.

I owe the greatest thanks to my parents. My mother has always been a source of unconditional support, and my late father, my hero, continues to guide me from above. This accomplishment is as much theirs as it is mine.

My heartfelt appreciation goes to Anjali, my partner and strongest motivator, whose constant encouragement gave me the strength to persevere. I am also grateful to my friends, especially Afonso, for the many insightful discussions, and Sangeen, whose idea of exploring AI tools such as Claude MCP proved instrumental in validating my concepts.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEC – Architecture, Engineering, and Construction

API – Application Programming Interface

AR – Augmented Reality

BEXEL – Building EXecution Lifecycle Manager (commercial BIM software)

BIM – Building Information Modelling

BOQ – Bill of Quantities

CAD – Computer-Aided Design

CDE – Common Data Environment

CSV – Comma-Separated Values

DBB – Design–Bid–Build

GA – Genetic Algorithm

GLTF – Graphics Language Transmission Format

GUI – Graphical User Interface

ICT – Information and Communication Technology

IFC – Industry Foundation Classes

IoT – Internet of Things

JSON – JavaScript Object Notation

LOD – Level of Development / Level of Detail

MCAS – Minimum Criteria for Attribute Similarity

MCP – Model Context Protocol

MR – Mixed Reality

QTO – Quantity Take-Off

RAW – Range of Attribute Weights

RIBA – Royal Institute of British Architects

SDK – Software Development Kit

SQL – Structured Query Language

SSMS – SQL Server Management Studio

US – United States

VR – Virtual Reality

1 INTRODUCTION

1.1 Background

The off-plan buyers commit large sums of money before a home is built, often without a chance to experience the finished space. The trust in such cases depends not only on legal agreements but also on how clearly the design is communicated and how reliably costs are explained. The traditional tools such as 2D drawings, brochures, 3D visuals, or milestone reports give only partial clarity. The buyers without technical knowledge often struggle to read layouts, imagine the spaces, or understand how their decisions affect costs (Puķīte and Geipele, 2017).

The buyers also want to visualise their space during construction, yet any changes requested within staged investment projects usually follow traditional channels such as phone calls, written notes, and paper-based approvals. The reliance on such methods disrupts the workflow and creates delays, while every modification also requires a recalculation of staged investment instalments. The absence of a transparent process for managing these updates often leads to cost overruns, confusion, loss of information, and declining trust between buyers and project teams.

The shortcomings of current practice are more visible in staged investment models where instalments are tied to construction milestones. The buyers expect clear proof that each payment reflects progress and that requested changes are priced fairly. The developers, on the other hand, need steady cash flow and processes that reduce disputes. The absence of transparent tools that link design choices to costs and staged payments often results in misunderstandings (Liu et al., 2021).

The Building Information Modelling (BIM) has become central to the architecture, engineering and construction industry. The integration of geometry, quantities, schedules, and cost data within a single model has been described as a “single source of truth.” The studies confirm that BIM improves efficiency, reduces errors, and supports reliable decision-making (Al-Roumi and Al-Sabah, 2024). The limitation is that BIM remains mainly a professional tool. The buyers rarely access it directly since authoring environments are too technical.

The residential sector highlights this gap most clearly. The research in Oman and Kuwait shows awareness of BIM but little application in housing. The projects where it is used rely on visualisation, clash detection, estimation, or scheduling rather than on cost transparency or buyer engagement (Al Harthy et al., 2020; Al-Roumi and Al-Sabah, 2024). The buyers therefore continue to depend on simplified marketing material that hides the impact of design changes. The trust is weakened exactly when confidence is most needed for staged payments.

The staged investment model also brings challenges of its own. The payments are tied to phases such as foundations, structural completion, and finishing works. The arrangement reduces financial risk but requires clear proof of progress and accurate accounting of design changes. The present practice still relies on manual updates, with sales staff recording requests, updating spreadsheets, and passing information to professionals. The process creates delays, duplicate records, and mismatches between buyer expectations and project data (Singh and Kaur, 2021).

The advances in digital standards now make new workflows possible. The Industry Foundation Classes (IFC) allow data exchange between platforms, while lightweight formats such as GLTF enable interactive visualisation in browsers. The combination of these technologies with classification-based cost databases creates opportunities for guided buyer edits with instant cost feedback. The approach promises clarity and control for buyers while developers retain technical oversight.

Figure 1-Buyer engagement workflow cycle

The present research builds on this potential. The study investigates whether BIM can be extended to support buyer communication in staged investment housing projects. The prototype is designed and tested through a real case study to examine controlled editing, live cost updates, and structured outputs that integrate into a Common Data Environment. The idea is that if buyers can see the financial impact of their choices transparently and in real time, then trust, engagement, and staged payments can all be improved.

1.2 Research Problem

The spread of digital platforms such as Planner 5D, Sweet Home 3D, Higharc, and RedesignUS has made it easier for buyers to visualise and configure their homes (Zainon et al., 2020; Old House New Home, 2020). The attraction of these tools lies in their simplicity, yet they remain disconnected from professional BIM environments. The edits made cannot be validated against technical rules or transferred directly into construction workflows, and the cost outputs are based on assumptions rather than classification-linked BIM data.

The professional platforms, including BEXEL Manager, CostX, and Autodesk Construction Cloud, provide detailed integration of cost and schedule but are too complex for non-technical buyers (Infrastructures, 2018). The result is a divided landscape in which consumer tools are easy to use but unreliable, while professional systems are accurate but inaccessible.

The difficulty becomes sharper in staged investment models, where payments are tied to milestones such as foundations, structure, and finishing works (Al Harthy et al., 2020). The process demands transparent updates on both progress and costs, yet current tools rely on static reports rather than live model data. The absence of clarity leads to mistrust and delayed decisions.

The behaviour of buyers adds another layer of complexity. The majority prefer guided changes within pre-designed units instead of unrestricted freedom, which often results in confusion or requests that clash with technical feasibility (Puķīte and Geipele, 2017).

The central research problem rests on three gaps. The consumer tools are accessible but disconnected from BIM. The staged investment model requires incremental cost feedback that current systems do not provide. The buyers need guided interaction rather than complete design freedom. The present dissertation addresses these gaps through a prototype that links classification-based cost data with safe buyer edits and produces verifiable outputs aligned with staged investment workflows.

1.3 Aim and Objectives

The aim of this research is to design and validate a prototype that bridges the gap between consumer-facing platforms and professional BIM workflows in staged investment housing projects. The intention is not to provide buyers with full design freedom but to create a guided environment where options can be explored, costs are updated transparently, and outputs can be reintegrated into professional systems without loss of data integrity.

The objectives of the research are:

1. The creation of a controlled interface where buyers can edit non-structural elements while structural components remain locked.
2. The integration of classification-based cost data so that each change triggers live recalculation and display of costs.
3. The generation of structured outputs in delta files suitable for upload into a Common Data Environment and linked to staged instalments.
4. The evaluation of the prototype in a case study, using one flat from a G+4 residential building to test performance, accuracy, and usability.

The combination of these objectives establishes a pathway from the identified gaps to a proof of concept that demonstrates how BIM can be extended to improve buyer engagement, cost transparency, and staged investment alignment.

1.4 Scope and Limitations

The scope of this research was deliberately narrowed to provide a clear proof of concept rather than a full commercial system. The focus was placed on staged investment housing projects, since these developments are highly sensitive to buyer–developer communication and often face disputes about design choices and instalment payments. A G+4 residential building was selected as the case study, with one flat extracted as the test unit. Within that flat, a kitchen partition wall and floor finishes were chosen as editable elements, as they represent common buyer modifications and offer a manageable scope for demonstration.

The workflow was structured around a digital pipeline in which the model was created in Revit, exported to IFC, converted to GLTF, and linked to a classification-based cost database. The process allowed buyers to make guided edits to non-structural elements while structural components remained locked. Each change was connected to live cost updates, and the results were exported in structured files suitable for integration into a Common Data Environment.

The limitations of the study arise from the restricted scope and technical fragility of the prototype. The system did not regenerate a fully consistent IFC model from edited GLTF files, meaning professional intervention was still required to maintain the authoritative model. Occasional parsing and rendering errors were also observed, showing that stability needs improvement. In addition, the range of editable options was limited, and the prototype was tested in a controlled setting rather than with actual buyers.

The study therefore demonstrates feasibility within a narrow boundary, while also pointing to areas for future development, such as scalability, technical robustness, and usability testing with real users.

1.5 Thesis Structure

The dissertation is organised into six chapters that build progressively from context to contribution. The first chapter introduces the background, research problem, aim, objectives, scope, and limitations. The second chapter reviews literature on BIM in residential projects, staged investment models, cost transparency, and buyer engagement, identifying the research gap. The third chapter sets out the methodology, explaining the design science approach, classification-based cost framework, and case study selection. The fourth chapter presents the prototype and its application to the case study, followed by Chapter Five, which discusses the findings, limitations, and practical implications. The final chapter concludes the research and outlines directions for future development.

2 LITERATURE REVIEW

2.1 Introduction

Buying a home is one of the biggest choices people make, not only in terms of money but also in personal commitment. For many households it reflects years of saving, attachment to a particular place, and expectations of how life will unfold inside the new home. In off-plan projects this decision comes before the building is even complete. Buyers must trust that what they see in drawings or models will match the finished product, that the agreed price will remain fair, and that each payment they release will genuinely reflect progress on site.

In reality, this trust is often fragile. Traditional methods of communication, such as static plans, brochures, or written updates, do not always capture the reality of a space. Buyers may misread layouts, misjudge room sizes, or overlook how a change in design could alter costs and timelines. In staged investment projects, where money is released in phases tied to milestones, these gaps in understanding can easily create disputes, delays, and a loss of confidence between buyers and developers.

At the same time, the industry already has tools that could help avoid these issues. Building Information Modelling (BIM) can link 3D visualisation with live data on cost and schedule, and immersive interfaces together with Common Data Environments (CDEs) can share up-to-date project information. Despite this, such resources usually stay within professional teams, leaving buyers with little or no direct access to the data that drives design and construction decisions.

This chapter therefore reviews the research and practice that relate to closing this gap. It looks at how BIM has been applied in residential design communication, where buyer interaction processes have been effective and where they have failed, and how cost transparency might be improved. It also considers the continuing difficulty of verifying milestones in staged investment projects, along with the potential of immersive interfaces and CDEs to make complex data understandable for non-specialists. The goal is to highlight what current tools can offer, what they lack, and how these weaknesses point to the need for a buyer-facing BIM platform that links design choices, cost transparency, and milestone tracking in a single environment.

2.2 BIM in Residential Design Communication

Building Information Modelling (BIM) has changed how buildings are imagined, designed, and delivered. Rather than relying only on flat 2D drawings, it provides a detailed 3D environment where geometry is combined with information on materials, specifications, schedules, and costs (Puķīte and Geipele, 2015). The model then serves not just as a visual guide but also as a central source of information for everyone involved in the project. For design teams, this approach helps reduce coordination mistakes between disciplines, improves the reliability of documentation, and makes it easier to assess the impact of changes before construction begins.

In residential construction, BIM offers opportunities that go beyond internal coordination between architects, engineers, and contractors. It can fundamentally change how buyers who are the end users of these projects experience and understand the design process. Buyers traditionally rely on sales brochures, printed plans and static 3D renders to imagine their future home. These formats often lack detail and can be open to misinterpretation. For example, a buyer reading a 2D plan may misunderstand the scale of a bedroom or the clearance space in a kitchen layout. Studies have shown that such misunderstandings are common among nontechnical stakeholders and can lead to disputes or late stage changes during construction (Eadie et al., 2015).

A survey of 42 AEC firms in Oman revealed a growing interest in BIM but highlighted persistent adoption barriers. The most cited obstacles were a lack of trained personnel (67%) and high initial software and training costs (58%). Respondents also mentioned inconsistent government mandates and the absence of a standardised BIM execution plan as challenges to full integration. While some firms reported improved visual communication with BIM, few had expanded its use to cost or scheduling functions. These findings show that regional readiness plays a key role in determining how effectively BIM can be integrated into buyer-facing workflows (Al Aamri et al., 2025).

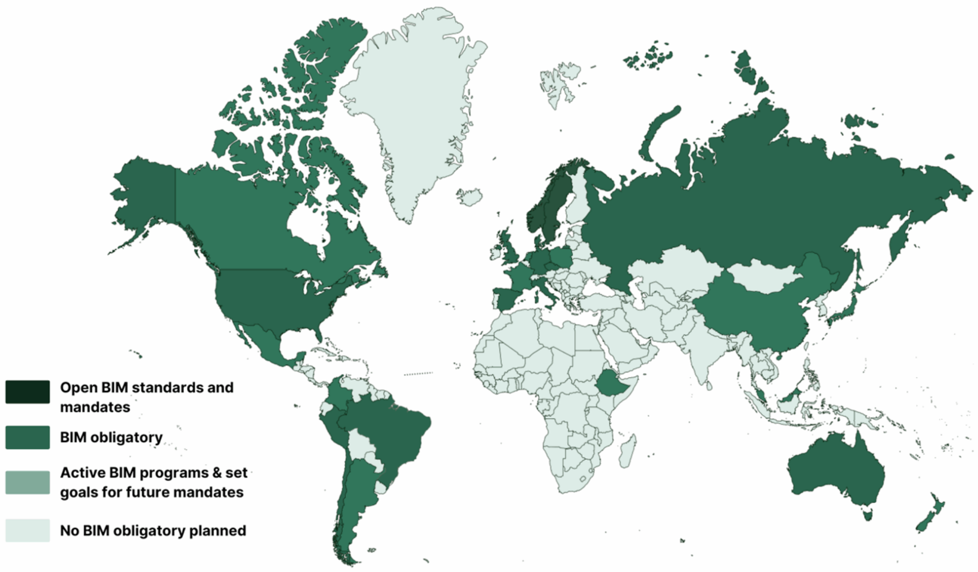


Figure 2-Global distribution of BIM mandates(Al Aamri et al., 2025).

The map shows how differently countries around the world are approaching BIM adoption. Some, like the United Kingdom, Germany, and Russia, already have strong mandates and open BIM standards in place, making digital processes a requirement for public projects. Others, including the United States, Canada, and Brazil, have made BIM obligatory in practice, though the way it is applied often varies across states or sectors. Countries such as India and South Africa are still in the process of developing their programs, setting clear goals for future implementation but not yet requiring it across the board. At the same time, much of Africa and parts of the Middle East have not yet planned mandatory BIM use, which highlights the uneven pace of global adoption. Overall, the picture suggests that while BIM has become a central part of construction in many advanced economies, other regions are still catching up, each moving forward at its own speed.

A 3D BIM model helps reduce many of the risks that occur when buyers rely only on drawings or static images. Unlike a single render, the model can be moved around, rotated, and zoomed into, giving a realistic sense of space, daylight, and proportion. In off-plan projects, where the building has not yet been built, this type of interactive view can provide buyers with greater confidence in their decisions. Studies of residential schemes show that immersive BIM visualisation allows stakeholders to confirm layouts and finishes at earlier stages, which shortens decision-making time and lowers the chances of late changes (Infrastructures, 2018).

The benefits of BIM also extend beyond 3D visualisation. When the model is connected to schedules (4D) and cost data (5D), it can show how construction is planned and immediately calculate the effect of design changes on both cost and delivery (Zainon et al., 2020). A simple example is the upgrade of a floor finish. In a 5D environment, the buyer sees not only the added cost of a premium option but also whether the change affects the completion of that stage. This creates a more transparent process in which the consequences of choices are visible before commitments are made.

Liu et al. (2021) proposed a framework to assess BIM's value during the design stage of residential buildings delivered under the Design–Bid–Build model. They identified five main dimensions—efficiency, cost control, design quality, collaboration, and stakeholder satisfaction—each measured with clear indicators. Their survey of 42 projects showed that design coordination provided the strongest benefit (4.63/5), followed by collaboration (4.47/5) and cost control (4.21/5). Importantly, buyer satisfaction was higher when 3D BIM visualisation was used during early consultation. This finding supports the argument that visual communication at the start of a project is essential for engaging buyers.

Yet in practice, these advanced features are rarely extended to buyers. Professional tools such as Autodesk Revit, Navisworks, or BEXEL Manager are built for trained designers and engineers. They are full of technical commands, industry terminology, and complex navigation that can easily overwhelm non-specialists (Digitalization and Automation in Construction, 2021). Even if buyers were given access, most would struggle to use the software without significant simplification.

This mismatch between BIM's technical potential and what buyers can realistically use is the central challenge of this research. A simplified, buyer-friendly interface could act as a common space where both professionals and buyers refer to the same updated model. In such an environment, buyers could explore their future homes, compare available options, and see the cost and schedule impact of each decision, while professionals would know that those decisions remain connected to reliable technical and financial data.

The advantages of such a system could be considerable. For developers, it offers a way to cut down on rework that often results from unclear communication and to avoid delays caused by repeated clarifications. For buyers, the value lies in greater transparency, along with the reassurance that the choices they make will be carried out as agreed.

2.3 Buyer Interaction and Customization in Housing Projects

Buyer interaction in residential projects describes how buyers take part in shaping the design and features of the homes they purchase. This can happen in many ways, from choosing finishes and fixtures to requesting changes in layouts. Developers have increasingly recognised that giving buyers a chance to customise certain aspects of their units can raise satisfaction, help projects stand out in a competitive market, and even justify higher prices (Zainon et al., 2020).

In larger multi-unit schemes, particularly those sold off-plan, this interaction usually begins during the sales stage and continues as design choices are confirmed before and during construction. Buyers may select floor or wall finishes, upgrade kitchens and bathrooms, adjust partitions, or pick built-in furniture options. These decisions go beyond appearance; they can affect sequencing on site, procurement schedules, and compliance with regulations.

Research shows that when customisation is offered in a structured way, buyers form stronger emotional ties to their homes and are more satisfied in the long term (Puķīte and Geipele, 2015). But if the process is poorly managed, the result can be confusion, delays, and higher costs for both sides. One example is when buyers are offered finish options without being told about delivery times or extra charges, leading them to choose items that later cause delays or require substitutions.

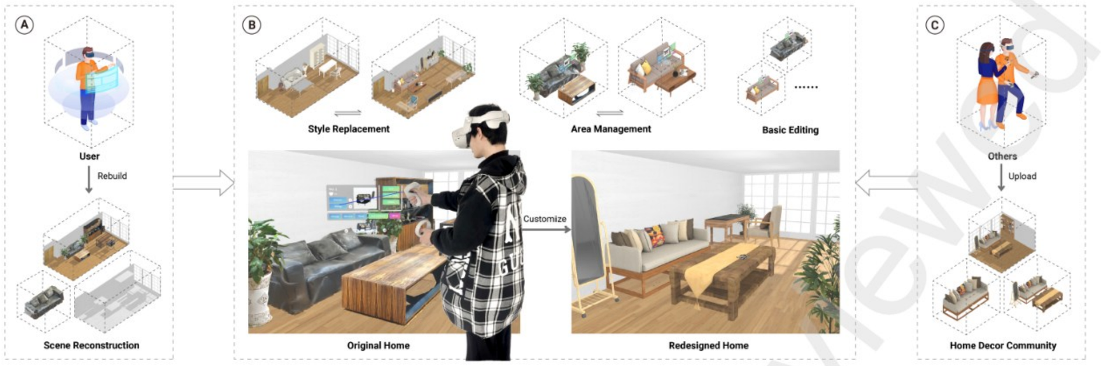


Figure 3- RedesignUS_ VR system_modify own homes. (You et al., 2023)

A major difficulty with current systems for recording buyer input is their fragmented nature. In many projects, choices are still gathered through paper forms, spreadsheets, or email chains, and then entered manually by the design team. This manual process opens the door to errors, such as wrong finish specifications or missed updates in the construction schedule (Eadie et al., 2015). In large developments with many units, the chance of such errors grows even higher.

Digital tools have begun to improve this situation. In some markets, developers now use customer relationship management (CRM) platforms linked with product catalogues. Web-based configurators also exist that let buyers pick finishes or layouts online and preview them in a simplified 3D model. Even so, most of these tools are not linked to the live BIM model used for design and construction (Zainon et al., 2020). As a result, the buyer's selections still have to be re-entered manually into the professional environment, which creates scope for inconsistencies between what the buyer sees and what is actually built.

Smaller residential projects also show the value of involving buyers earlier through BIM. Patil et al. (2019) applied BIM on a G+1 residential building, using Autodesk Revit to create 3D views, schedules, and quantity take-offs before work started. The owner was able to check and approve the layout, finishes, and room configurations in advance, which reduced design changes during construction by more than 20 percent. The BIM model also generated an accurate bill of quantities, improving cost estimation by around 15 percent compared to manual methods. These results indicate that even in modest projects, BIM can support clearer decision-making and stronger buyer–developer communication.

Another key issue is the scope of customisation offered. Full design freedom may appear attractive but often leads to requests that are either technically unfeasible or too costly. Moving a partition wall without considering mechanical or plumbing systems, for example, can cause major coordination problems. Best practice is to allow changes within defined limits such as finishes and non-structural elements while keeping core systems fixed (Puķīte and Geipele, 2015). This approach gives buyers meaningful choice but still protects construction efficiency.

In staged investment projects, buyer interaction becomes even more important. Since payments are tied to milestones, many buyers expect to confirm or adjust their design decisions at several points during construction. Most current systems are not set up for this kind of incremental decision-making. They usually rely on one-off choices made early in the project, and progress is communicated through written reports that can be interpreted in different ways. This lack of clear visual confirmation often leads to disputes about whether milestones have been met.

An integrated, buyer-facing BIM platform could help address these issues. By linking buyer decisions directly to the live model, the cost database, and the schedule, such a system would allow buyers to explore valid options within the limits set by the design team. They could immediately see the effect of their choices on costs and delivery dates and confirm completed work visually before releasing payments. This would cut down on manual data handling, reduce errors, and give both buyers and developers a clearer, shared view of project status something that current methods still fail to achieve.

The experience from Kuwait further illustrates these challenges. While BIM adoption was reported at 78 percent, only 24 percent of firms used it beyond basic 3D visualisation. Integration with cost and schedule data was rare, limiting its role in collaboration and decision-making. One pilot tested predefined 4D scheduling templates for tract housing and achieved an average 12 percent time saving during planning. Even so, the study concluded that without stronger links to cost and schedule management, BIM risks being seen as just a presentation tool rather than a genuine support system for collaborative decisions (Al-Roumi and Al-Sabah, 2024).

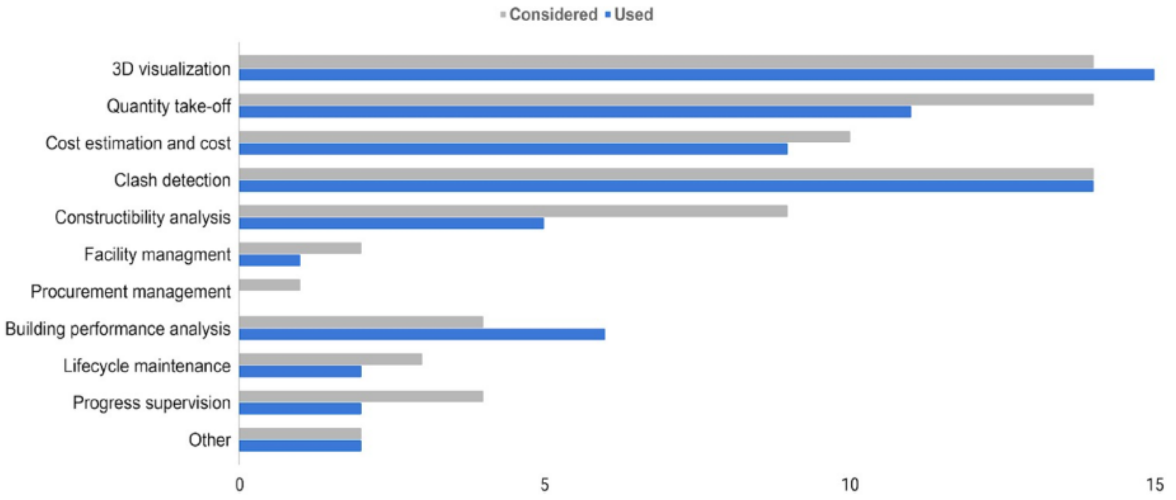


Figure 4- BIM applications used by organizations versus applications considered by organizations. (Al-Roumi and Al-Sabah, 2024)

2.4 Enhancing Cost Transparency in Residential Projects

Cost transparency in residential construction refers to the clear, timely, and accurate communication of financial information to all project stakeholders, particularly buyers. In many projects, especially those sold off-plan or developed under staged investment models, cost transparency plays a critical role in building trust and supporting informed decision-making. Buyers committing to a property before it is built want reassurance that the price they agreed upon reflects actual construction realities, and that any changes they request will be priced fairly and promptly (Puķīte and Geipele, 2015).

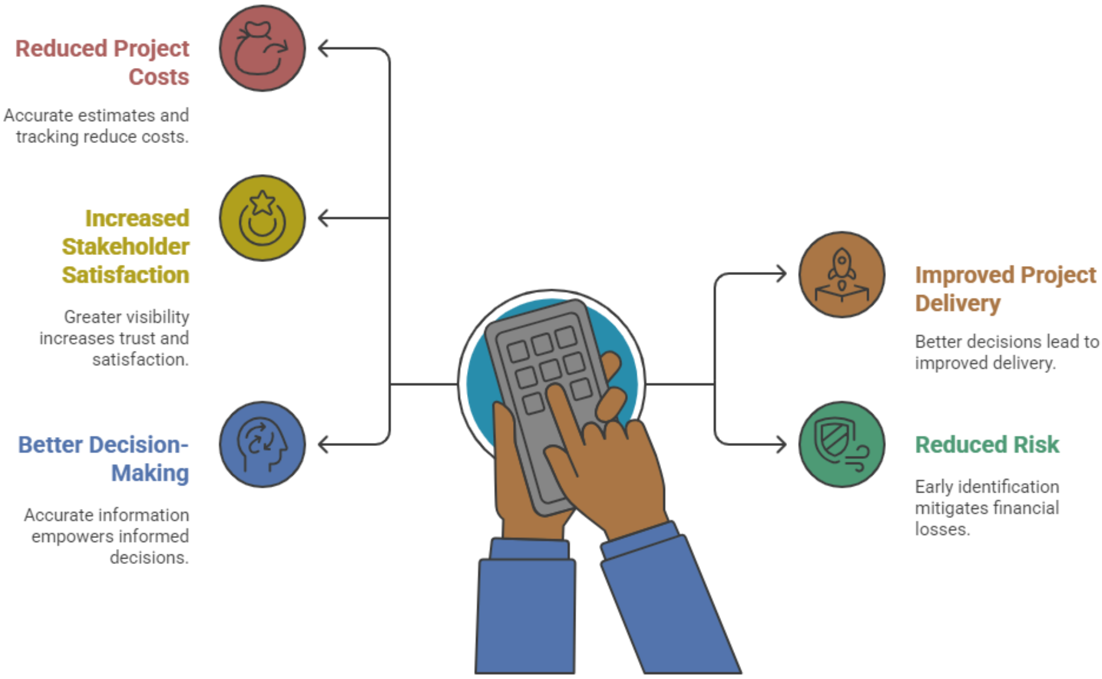
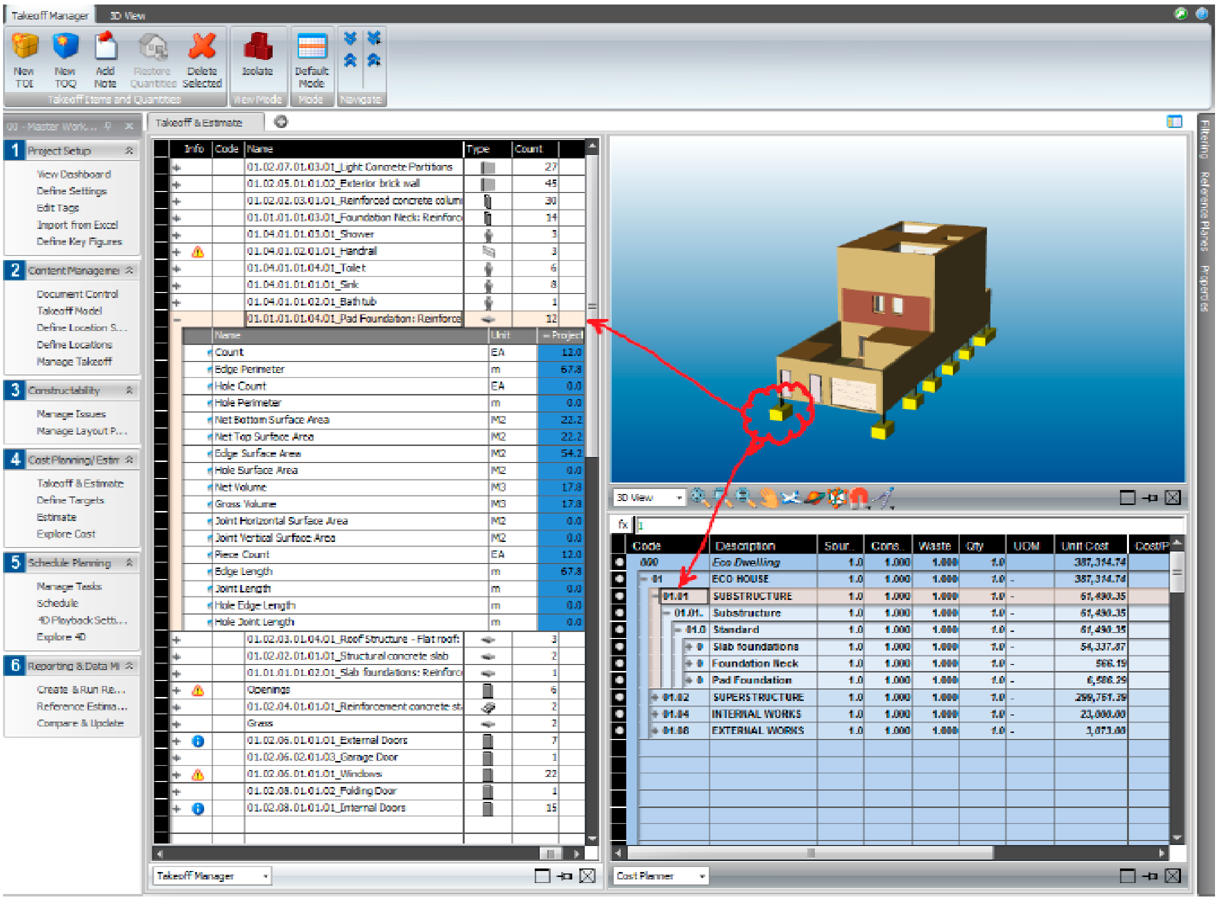


Figure 5- Benefits of cost transparency

Despite its importance, cost transparency is often limited in traditional workflows. Buyers typically receive cost information in the form of summary quotes, invoices, or ad-hoc updates from sales or project managers. These are usually detached from the design visualisations the buyer sees, making it difficult to connect a change in layout or materials to its financial impact (Eadie et al., 2015). This separation between design and cost data can lead to situations where buyers approve design changes without fully understanding their cost implications, or where disputes arise over unexpected increases in the final price.

BIM, particularly in its 5D form, offers a technical solution to this problem. By linking each element in the model to a cost database as shown in figure below, any change in geometry, material, specification can trigger an automatic update of the associated cost. For example, if a buyer selects a different type of tile for a bathroom, the system can instantly recalculate the total cost for that item, including labour and installation, and update the overall project cost accordingly (Infrastructures, 2018). This process not only speeds up cost estimation but also ensures accuracy by using standardised measurement and pricing data.



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+		01.01.01.01.03.01_Foundation Neck: Reinforc		14
+		01.04.01.01.03.01_Shower		3
+ ⚠		01.04.01.02.01.01_Handrail		3
+		01.04.01.01.04.01_Toilet		6
+		01.04.01.01.01.01_Sink		8
+		01.04.01.01.02.01_Bathtub		1
−		01.01.01.01.04.01_Pad Foundation: Reinforc		12

Name	Unit	Project
Count	EA	12.0
Edge Perimeter	m	67.8
Hole Count	EA	0.0
Hole Perimeter	m	0.0
Net Bottom Surface Area	M2	22.2
Net Top Surface Area	M2	22.2
Edge Surface Area	M2	54.2
Hole Surface Area	M2	0.0
Net Volume	M3	17.8
Gross Volume	M3	17.8
Joint Horizontal Surface Area	M2	0.0
Joint Vertical Surface Area	M2	0.0
Piece Count	EA	12.0
Edge Length	m	67.8
Joint Length	m	0.0
Hole Edge Length	m	0.0
Hole Joint Length	m	0.0

Info	Code	Name	Type	Count
+		01.02.03.01.04.01_Roof Structure - Flat roof:		3
+		01.02.02.01.01.01_Structural concrete slab		2
+		01.01.01.01.02.01_Slab foundations: Reinforc		1
+ ⚠		Openings		6
+		01.02.04.01.01.01_Reinforcement concrete st		2
+		Grass		2
+ ⓘ		01.02.06.01.01.01_External Doors		7
+		01.02.06.02.01.03_Garage Door		1
+ ⚠		01.02.06.01.01.01_Windows		22
+		01.02.08.01.01.02_Folding Door		1
+ ⓘ		01.02.08.01.01.01_Internal Doors		15

Code	Description	Sour..	Cons..	Waste	Qty	UOM	Unit Cost	CostP
000	*Eco Dwelling*	1.0	1.000	1.000	1.0		387,314.74	
− 01	ECO HOUSE	1.0	1.000	1.000	1.0	-	387,314.74	
− 01.01	SUBSTRUCTURE	1.0	1.000	1.000	1.0	-	61,490.35	
− 01.01.	Substructure	1.0	1.000	1.000	1.0	-	61,490.35	
− 01.0	Standard	1.0	1.000	1.000	1.0	-	61,490.35	
+ 0	Slab foundations	1.0	1.000	1.000	1.0	-	54,337.87	
+ 0	Foundation Neck	1.0	1.000	1.000	1.0	-	566.19	
+ 0	Pad Foundation	1.0	1.000	1.000	1.0	-	6,586.29	
+ 01.02	SUPERSTRUCTURE	1.0	1.000	1.000	1.0	-	299,761.39	
+ 01.04	INTERNAL WORKS	1.0	1.000	1.000	1.0	-	23,000.00	
+ 01.08	EXTERNAL WORKS	1.0	1.000	1.000	1.0	-	3,073.00	

Figure 6- Cost mapping with classification code & 3D model (Park et al., 2020)

Research into decision-driven cost modelling supports the argument for linking buyer choices directly to project cost data. One framework proposes structuring cost estimation around anticipated owner decisions, with each option carrying predefined cost and schedule implications. This approach allows for more predictable budgeting and reduces the risk of disputes, as owners can see the financial consequences of their selections before confirming them (Development of Cost Model on Owners' Decision, 2018). Such methods align closely with the principles of real-time 5D BIM cost feedback but remain rare in consumer-facing platforms.

However, in practice, these capabilities are almost exclusively used by project teams quantity surveyors, cost managers, and contractors rather than buyers. Professional cost estimation tools such as CostX, BEXEL Manager are powerful but highly technical, requiring training to navigate and interpret results (Digitalization and Automation in Construction, 2021). As a result, buyers rely on filtered reports that summarise the cost data, often without showing the detailed breakdown or linking it directly to the visual model.

Park et al. (2020) proposed an advanced 5D BIM workflow that embeds quantity take-off, cost estimation, and scheduling data directly into the model from the earliest design stages. Tested on a residential pilot project, this approach reduced cost reporting times from several days to under two hours and allowed for rapid scenario testing of material and design alternatives. The model supported real-time updates to cash flow forecasts, enabling buyers and developers to immediately see the cost and time impact of any design modification. This responsiveness is particularly advantageous in staged investment models, where timely financial clarity can prevent disputes.

A further limitation is that many cost estimates are static snapshots rather than live updates. In dynamic construction environments, material prices, labour rates, and procurement timelines can shift rapidly. Without a real-time connection between the cost database and the buyer-facing interface, the information the buyer receives can quickly become outdated, leading to frustration when the actual invoice differs from the earlier estimate (Zainon et al., 2020).

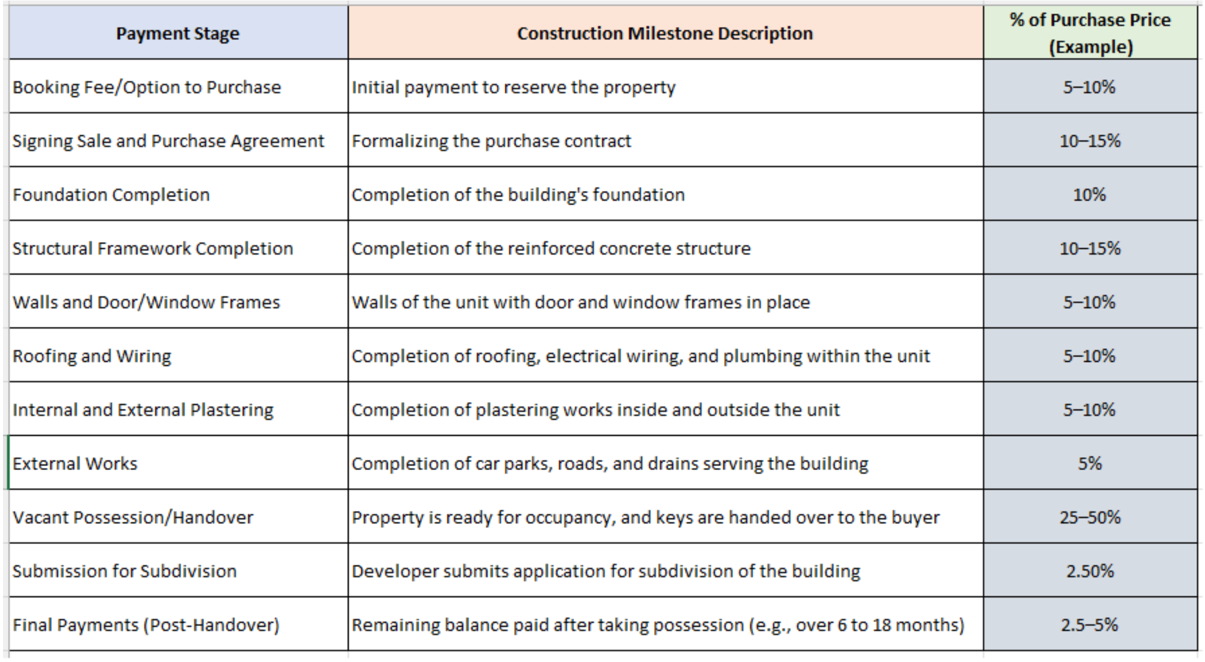
Sharma and Goyal (2019) compared conventional planning practices with BIM-based scheduling and cost tracking in residential projects. They found that BIM adoption led to average reductions of 18 percent in delays and 14 percent in cost overruns. The improvements came from the system’s ability to recalculate budgets and timelines automatically when design elements were changed, giving teams the chance to adjust schedules and payment milestones straight away. In staged investment projects, where payments are released gradually as progress becomes visible, this reduced the time lost in securing approvals. The study concluded that 5D BIM can act as a proactive control mechanism, helping teams identify risks to cost and time at an early stage.

Beyond technical benefits, research also underlines the psychological side of cost transparency. Buyers are more likely to trust developers when the basis for prices is made clear and the figures remain consistent across different communications (Puķīte and Geipele, 2015). In staged investment projects this trust carries even greater weight, since payments are linked to milestones. If buyers are able to see for themselves that a stage is complete and review the cost breakdown for it, they tend to release funds with more confidence, which in turn helps the developer maintain steady cash flow.

Jununkar et al. (2017) demonstrated a 5D BIM approach that combined 3D design, 4D scheduling, and 5D cost estimation into one coordinated process. Using Autodesk Revit, Navisworks, and Microsoft Project, they achieved real-time cost monitoring alongside schedule simulation. Their case study showed that the time needed for progress reporting was cut by 40 percent and that the accuracy of quantity take-offs improved by about 15 percent compared with manual approaches. The integration also made it easier to align staged payments with actual progress on site.

2.4.1 Communication Challenges in Staged Investment Models

In staged investment models, the full purchase price of a home is broken into several instalments, each linked to a specific stage of construction. For instance, a buyer may pay 5–10 percent at the time of booking, another 10 percent once the foundation is completed, 30 percent when the finishing works are installed, and the balance of 20 percent at handover. The figure below illustrates how such payments are typically distributed across stages. This approach is widely used in markets where homes are sold off-plan, as it eases the financial load on buyers and offers some protection if the project faces delays or is stopped midway (Al Harthy et al., 2020).



Payment Stage	Construction Milestone Description	% of Purchase Price (Example)
Booking Fee/Option to Purchase	Initial payment to reserve the property	5–10%
Signing Sale and Purchase Agreement	Formalizing the purchase contract	10–15%
Foundation Completion	Completion of the building's foundation	10%
Structural Framework Completion	Completion of the reinforced concrete structure	10–15%
Walls and Door/Window Frames	Walls of the unit with door and window frames in place	5–10%
Roofing and Wiring	Completion of roofing, electrical wiring, and plumbing within the unit	5–10%
Internal and External Plastering	Completion of plastering works inside and outside the unit	5–10%
External Works	Completion of car parks, roads, and drains serving the building	5%
Vacant Possession/Handover	Property is ready for occupancy, and keys are handed over to the buyer	25–50%
Submission for Subdivision	Developer submits application for subdivision of the building	2.50%
Final Payments (Post-Handover)	Remaining balance paid after taking possession (e.g., over 6 to 18 months)	2.5–5%

Figure 7-Stage investment payment phases

While staged investment can benefit both buyers and developers, it also introduces significant communication challenges. For the buyer, each payment decision depends on understanding whether the agreed milestone has truly been reached. In traditional workflows, this verification is often based on written progress reports or static photographs provided by the developer. These reports may lack detail, omit certain works, or be presented in ways that are open to interpretation. Without a clear, verifiable link between the milestone definition and the actual on-site progress, disputes can arise over whether payment is due.

For developers the challenge is different but equally critical. Delays in payment often caused by buyers requesting additional proof or raising concerns about incomplete work can disrupt cash flow, affect procurement schedules, and slow down construction. In large scale residential projects, where dozens or even hundreds of units are being delivered in parallel, these delays can compound and significantly affect project timelines (Puķīte and Geipele, 2015).

Research suggests that visual communication tools can improve milestone verification by giving buyers a clearer, more objective view of completed work (Eadie et al., 2015). For example, linking progress photographs to specific model elements in a 4D BIM environment allows buyers to see not only what has been built but also when it was built and how it fits into the agreed construction sequence. However, these approaches are rarely extended into buyer-facing platforms. Most BIM-based milestone tracking remains internal to the project team, with outputs provided to buyers as simplified summaries or static images.

A further challenge in staged investment projects is that buyers are often required to make decisions at different points during construction. For example, they may confirm finishes at an early stage but leave choices such as lighting layouts or built-in storage until the relevant phase of work begins. At present, these later decisions are usually handled through separate channels like emails or face-to-face meetings rather than within a single coordinated system. This fragmented process makes it easier for errors to occur, deadlines to be missed, and misunderstandings to develop.

A buyer-facing BIM platform could help resolve these issues by bringing milestone verification and design choices together in one interface.

2.5 Immersive Interfaces for Buyer Engagement

Immersive interfaces use interactive 3D environments, virtual reality (VR), augmented reality (AR) to give users a richer and more realistic experience of a space than static drawings or renders can provide. In residential projects, these technologies can play a major role in helping buyers visualise their future homes, understand design options, and make informed decisions. The ability to walk through a space virtually, examine finishes up close, view changes in real time can bridge the gap between technical design data and the buyer’s personal understanding of the project (Old House New Home, 2020).

Several studies have shown that immersive visualisation improves comprehension for nontechnical stakeholders. When buyers can explore a space at full scale, they can more accurately judge proportions, furniture layouts and circulation patterns (Zainon et al., 2020). For example, a kitchen layout that appears acceptable in a 2D plan may feel cramped when viewed in a VR environment, prompting the buyer to request changes before construction begins. This early detection of design concerns reduces the risk of costly modifications later in the project.

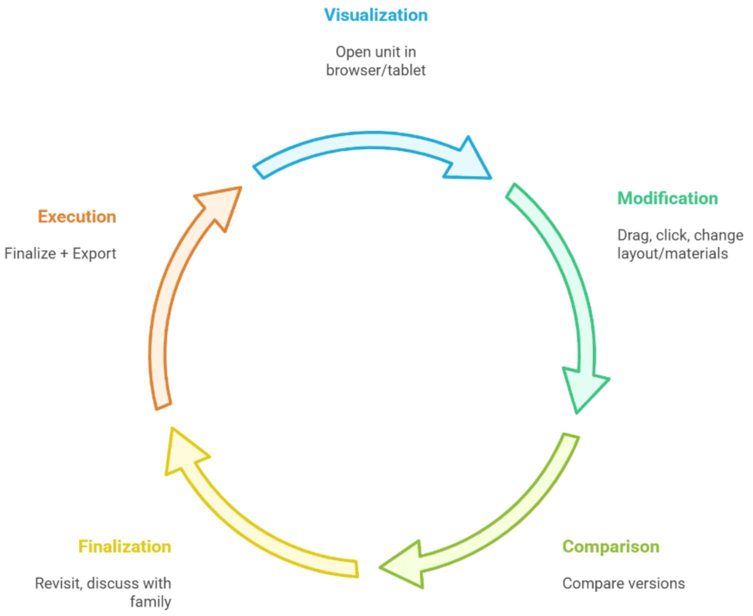


Figure 8- Design cycle

Immersive technologies also enhance emotional engagement. Buying a home is not only a financial transaction but also a personal and emotional decision. When buyers can see and experience their space in detail, they are more likely to feel connected to it, which can strengthen their commitment to the purchase (Puķīte and Geipele, 2015). Developers can use this engagement to maintain buyer interest during long construction periods, especially in staged investment projects where ongoing trust is essential.

Different immersive platforms vary in their accessibility and technical integration. High end VR solutions, such as those using dedicated headsets, offer the most immersive experience but require specialised equipment and trained staff. This makes them suitable for sales centres or showrooms but less practical for everyday buyer interaction. Web based 3D tools, by contrast, can be accessed from any standard device with an internet connection. While they may not provide the same level of realism as high-end VR, they are easier to deploy widely and can be integrated with live BIM data (Digitalization and Automation in Construction, 2021).

Despite their benefits most immersive buyer experiences are still disconnected from the underlying BIM model used for design and construction. Many VR and 3D tools operate as visual layers built from exported model data. This means that when changes occur in the BIM environment such as updates to wall positions, materials and fixtures these changes must be manually updated in the immersive model.

Without this synchronisation, buyers risk making decisions based on outdated information, undermining the trust these tools are meant to build.

Using immersive interfaces directly with the live BIM model could resolve this issue. In such a system, buyers would not only explore their space in real time but also see accurate, up-to-date information about costs, schedules, and available options. For example, selecting a new floor finish in the 3D environment could trigger an immediate cost update and schedule adjustment, all pulled from the same data the project team uses. This would turn the immersive interface from a purely visual tool into a functional decision-making platform.

2.5.1 Role of Common Data Environments (CDE) in Residential BIM

A Common Data Environment (CDE) is a central platform used to collect, manage, and share project information among all stakeholders. In a BIM-enabled project, the CDE becomes the single source of truth for drawings, models, schedules, specifications, and related documents (ISO 19650, 2018). Its purpose is to ensure that everyone works with the most current, approved information, reducing the risk of errors caused by outdated or conflicting data.

In residential construction, the CDE typically serves architects, engineers, contractors, and project managers. It enables them to upload and retrieve model updates, review mark-ups, and track revisions in real time. Popular CDE platforms include Autodesk Construction Cloud, BIM 360, and Dalux, each offering a mix of model viewing, document control, and workflow management features. When used correctly, the CDE not only improves coordination between professional teams but also provides a complete digital record of the project from design through to handover (Digitalization and Automation in Construction, 2021).

The Common Data Environment (CDE) has strong potential to improve communication with buyers, but in practice this role is still limited. Most buyers are not given direct access, and when access is allowed, it usually takes the form of static PDF drawings or restricted model views. While this protects sensitive technical and contractual details, it also prevents buyers from experiencing the real-time updates that make the CDE valuable for project teams. As a result, communication with buyers still depends on manually prepared reports, email exchanges, or presentations, all of which can lead to delays and mistakes.

Research suggests that role-based access can help overcome these limitations by controlling what different users are able to see in the CDE (Eadie et al., 2015). For buyers, this could take the form of a dedicated portal showing only the information relevant to their unit, such as approved design choices, current progress, and upcoming decisions. A filtered view of this kind could also connect directly to the same 3D model used by the project team, ensuring that what the buyer sees matches what is being built.

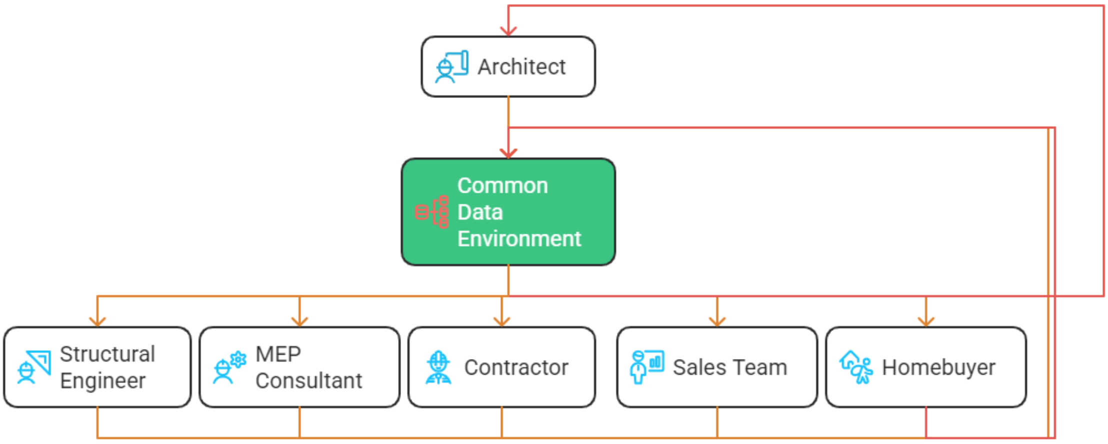


Figure 9- CDE interaction in residential building

In staged investment models, this kind of role-based buyer access could also be used to verify construction milestones. For example, when a milestone is reached, the project team could mark the relevant model elements as complete within the CDE. The buyer, logging into their portal, could see those elements highlighted in the model alongside photographs or site reports. This would provide a verifiable, model-based confirmation that the agreed work has been done, reducing the risk of disputes over payment releases (Al Harthy et al., 2020).

Despite these possibilities, very few residential projects implement CDE-buyer integration in practice. Where it has been attempted, the interfaces are often too technical for non specialists, and the process for updating buyer facing content is manual rather than automated. This limits the value of the CDE as a live communication tool for buyers.

2.5.2 Integration of CDE and Buyer Interfaces

Linking the Common Data Environment (CDE) with a buyer-facing interface represents a logical next step for making residential BIM more transparent and interactive. At present, the CDE functions as the central source of design, cost, and schedule information for professional teams, yet buyers typically see only fragments of this data through indirect channels such as emailed PDFs, progress reports, or static 3D images that are not connected to the live model (Digitalization and Automation in Construction, 2021).

A well-designed integration would give buyers access to selected parts of the CDE through a simplified portal tailored to their needs. Instead of navigating a professional environment full of technical detail, they would use a clear interface that shows only what is relevant—for example, the model of their unit, approved options for customisation, and current milestone progress. Role-based permissions could protect sensitive information while ensuring that buyers still receive accurate, up-to-date data (Eadie et al., 2015).

The technical benefits of such integration are clear. By connecting directly to the CDE, the buyer's view would update automatically whenever the professional model changes. This avoids the need for repeated manual exports and reduces the chance of discrepancies between what buyers see and what is actually built. It would also allow approved changes—such as a finish upgrade or a partition adjustment—to appear simultaneously in the buyer's portal and the professional model, keeping all stakeholders aligned.

From a process standpoint, CDE integration could reshape how staged investment models are managed. Rather than sending photos or issuing written milestone confirmations, developers could mark completed works directly in the model within the CDE. Buyers, logging into their portal, would then see those updates highlighted in 3D, with linked photographs or even short video clips for additional verification. This would provide clear evidence that milestones had been reached, reduce disputes, and speed up payment approvals (Al Harthy et al., 2020).

Such integration also opens up more advanced workflows. For instance, if a milestone involves kitchen cabinetry, the system could prompt buyers to confirm their finish choice before that stage begins. The interface could show available options, associated costs, and delivery impacts, all drawn directly from the CDE's cost and schedule data. Once confirmed, the decision would be recorded in the CDE, automatically adjusting procurement and sequencing.

Despite these advantages, very few projects show full integration of CDEs with buyer interfaces. Where attempts have been made, they tend to involve partial connections, with manual steps still required to pass information from the professional environment to the buyer-facing view. Overcoming this gap requires both technical solutions, such as APIs and automated data flows, and organisational changes so that the CDE is treated as a communication platform rather than only a professional tool.

Singh and Kaur (2021) provide an example of how this could be extended further. They presented a framework that linked BIM with Value Engineering (VE) to optimise choices for both performance and cost. In a residential case, BIM was used to create alternative façade and interior configurations, each evaluated for cost, durability, and maintenance. The VE-BIM approach identified material substitutions that lowered façade costs by 12 percent while maintaining quality. Embedding such optimisation processes within CDEs would allow buyers to review curated, cost-efficient options without compromising technical standards.

2.6 Buyer-Facing BIM Platforms: Current Tools and Gaps

In recent years, several digital platforms have emerged with the aim of involving buyers more directly in the design and customisation of their homes. These can be broadly grouped into two categories:

1. Consumer oriented 3D home design tools that focus on accessibility and visual appeal.
2. Professional grade BIM platforms adapted to allow limited buyer interaction.

Consumer oriented tools, such as Planner 5D, Sweet Home 3D, and RedesignUS, provide intuitive drag-and-drop interfaces that allow users to experiment with layouts, finishes, and furniture arrangements (Zainon et al., 2020; Old House New Home, 2020). These systems are easy to use and require no prior technical knowledge. They help buyers visualise their ideas and engage creatively with their future homes. However, these tools generally operate outside the professional BIM environment. They are often built on simplified geometry and do not carry the full data structure such as material specifications, classification codes, or embedded cost information that would make their outputs directly usable in construction. As a result, changes made in these platforms must be re-modelled manually in the project's official BIM system, creating inefficiencies and opportunities for error.

On the other end of the spectrum are professional BIM platforms like Autodesk Construction Cloud, BIM 360, and Dalux, which have begun to offer limited buyer-facing features. These tools maintain the integrity of the professional model, ensuring that all elements remain technically valid and linked to their associated data. In some cases, buyers are given restricted access to view models, comment on design elements, or approve certain changes (Digitalization and Automation in Construction, 2021). While these systems are powerful, their complexity often makes them difficult for non-specialists to navigate, and the buyer experience can feel overwhelming or unintuitive.

Between these two extremes lies a noticeable gap. There are very few platforms that combine the **ease of use** of consumer tools with the **technical integration** of professional BIM environments. This gap becomes more apparent when considering staged investment models, where buyers need to interact with the design not just once at the beginning of the process, but at multiple points throughout construction. Most existing tools are designed for one time configuration rather than ongoing decision making and milestone verification.

The limitations of current systems are not only technical but also procedural. In many cases, buyer interactions within digital platforms remain separate from the live BIM model, so updates are not carried through automatically into the construction workflow. Cost data, when it is provided, is usually presented as a fixed figure rather than a live calculation linked to actual quantities and unit prices. Without this real-time link, buyers are unable to judge the true financial impact of their decisions.

Another weakness is that most buyer-facing platforms have little or no direct integration with the project's Common Data Environment (CDE). Where some level of connection does exist, it is often limited to simple document sharing or viewing static model snapshots, without the deeper functionality needed to tie buyer choices into procurement, scheduling, and cost control. The absence of this integration means that important opportunities for automation and error reduction are lost.

The following section offers a comparative review of several tools currently in use. It examines how well they support buyer engagement in residential projects and highlights the shortcomings that this research seeks to address.

2.6.1 Comparative Tool Analysis

To understand where current buyer-facing platforms succeed and where they fall short, it helps to compare a set of commonly used tools from both consumer-oriented and professional categories. The comparison in this study looks at five main criteria, each drawn from the requirements of staged investment residential projects.

1. Ease of use for non technical buyers
2. Integration with live BIM data
3. Real time cost feedback
4. Support for constraint based customisation
5. Integration with a Common Data Environment (CDE)

Consumer Oriented Tools

Planner 5D, Sweet Home 3D, and RedesignUS are representative of consumer-oriented platforms. Their primary advantage is accessibility buyers can create or modify layouts, experiment with finishes, and view designs in 3D without training (Zainon et al., 2020; Old House New Home, 2020). These tools provide an engaging visual experience and support creative exploration, making them useful for conceptualising ideas early in the buying process. However, they lack live links to the professional BIM model. The geometry is often simplified, metadata is absent, and there are no embedded classification codes or procurement data. Changes made in these systems cannot be directly implemented in construction without manual re-modelling, introducing inefficiency and the risk of misinterpretation.

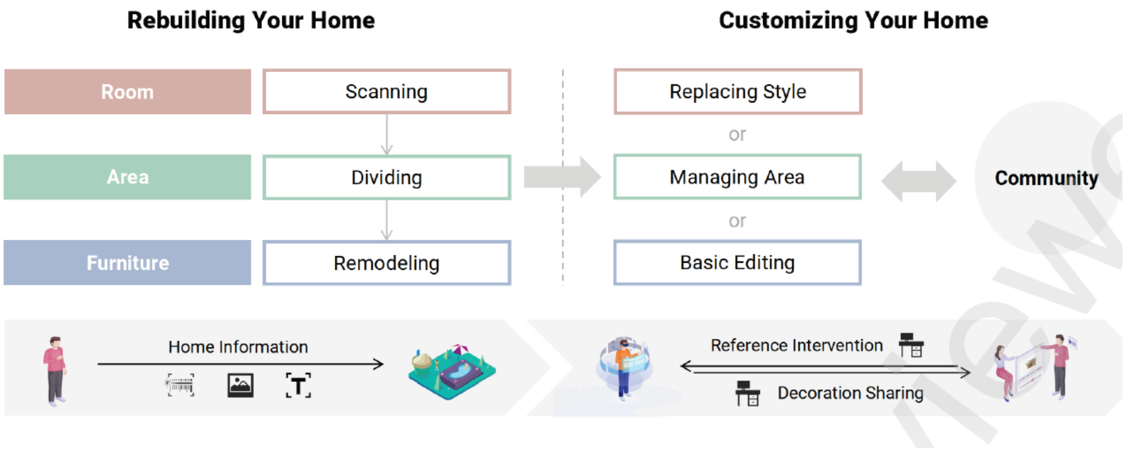


Figure 10- The framework of RedesignUS. (You et al., 2023)

Professional BIM Platforms

Platforms such as Autodesk Construction Cloud, BIM 360, Dalux, and BEXEL Manager are designed primarily for professional coordination but offer varying degrees of buyer interaction (Digitalization and Automation in Construction, 2021). In some cases, buyers are given controlled access to view models, approve design options, or comment on elements. These tools ensure that all changes remain within the bounds of technical feasibility and maintain a direct connection to live BIM data. However, their complexity, technical terminology, and multi-layered navigation can be intimidating for non-specialist users. Moreover, while cost and schedule data may be available in the backend, it is rarely presented in a simplified, buyer-friendly way.

Niche and Hybrid Solutions

Some tools attempt to bridge the gap by simplifying professional BIM data for buyer use. For example, Dalux offers limited “customer portal” features, and certain custom-built web platforms integrate BIM exports into user-friendly interfaces. While these solutions are promising, they often suffer from partial integration. Data synchronisation may not be automatic, and the scope for buyer customisation is frequently restricted to finishes and colours, without the ability to make layout adjustments within predefined constraints.

Comparative Findings

The comparison shows that no existing platform meets all five criteria. Consumer tools excel in ease of use but fail in technical integration and real-time cost linkage. Professional platforms excel in technical accuracy but fail in accessibility and user-friendliness. Hybrid solutions address some issues but often fall short on automation and live synchronisation with the CDE.

This gap is especially critical in staged investment models, where buyers need to make informed decisions at multiple stages, verify milestone completion, and understand the financial implications of their choices instantly. None of the reviewed tools fully integrate buyer interaction with live BIM data, real-time cost updates, constraint-based editing, and CDE linked milestone tracking in a single, accessible platform.

2.7 Research Gaps

In the last decade, Building Information Modelling (BIM) has transformed how architects and engineers design and coordinate buildings. Digital tools now make it possible to manage layouts, detect clashes, link designs to schedules, and estimate costs with high precision (Puķīte and Geipele, 2015; Eadie et al., 2015). However, these platforms have been developed primarily for professional use. Buyers the end users of residential spaces remain largely excluded from the benefits of live, data-driven design environments.

Some tools have tried to close this gap. Consumer facing platforms such as Planner 5D, Higharc, Sweet Home 3D, and RedesignUS allow users to explore spaces in 3D, change finishes, rearrange layouts, and experiment with furniture placement (Zainon et al., 2020; Old House New Home, 2020). These interfaces feel modern and engaging, but they are disconnected from the BIM models used for construction. As a result, changes that appear feasible on-screen may be structurally or technically invalid in reality. For instance, a buyer might remove a partition wall that conceals a plumbing riser or alter a wall that contributes to lateral stability. Because the system has no embedded technical constraints, such changes are rejected later during the technical review stage.

Professional grade BIM and cost management platforms such as BEXEL Manager, CostX, or Autodesk Construction Cloud operate at the opposite end of the spectrum. These systems can link every model element to cost data, schedule sequences, and procurement records, allowing real-time pricing updates when changes occur (Infrastructures, 2018). However, buyers rarely interact with these tools. In most projects, their requests such as selecting a finish or adjusting a layout are passed through sales teams, manually entered into spreadsheets, and then relayed to the design team. This multi-step process slows decision-making and increases the risk of errors, particularly in large housing developments where many units are being customised in parallel.

The problem is compounded in staged investment models. Here, buyers release funds gradually as construction milestones are achieved (Al Harthy et al., 2020). Yet most customisation platforms are designed for one-off decisions made early in the project and do not allow incremental updates at different stages. Nor do they provide clear, verifiable evidence of work completed for each milestone. Payment decisions are often based on static reports rather than model-based verification, leading to confusion, mistrust, and delays.

Even Common Data Environments (CDEs) such as BIM 360 and Dalux which are intended to connect all project stakeholders rarely extend full functionality to buyers. While some developers have experimented with buyer access, the interfaces are often too technical, and the process for updating content remains manual. Buyer feedback is frequently collected outside the CDE and entered later, breaking the live data flow and undermining the purpose of a single source of truth (Digitalization and Automation in Construction, 2021).

The result is a clear and persistent gap: there is no single platform that connects a buyer's design choices directly to the live technical and financial systems used to deliver their home. No existing system enables buyers to explore valid options within defined constraints and to see, in real time, how their choices affect cost, schedule, and construction feasibility while also providing milestone verification for staged payments.

This research proposes to address that gap by developing a buyer facing platform that combines the accessibility of consumer tools with the data integrity of professional BIM systems. It will:

- Allow constraint based, layer level editing of non-structural elements.
- Link each editable element to classification-based cost data.
- Provide real time cost and schedule updates.
- Synchronise changes directly with the project's CDE.
- Offer model-based milestone verification for staged investment decisions.

By combining these capabilities in a single, integrated environment, the proposed solution aims to reduce rework, speed up decision making, and rebuild trust between developers and buyers in residential projects.

2.7.1 Summary of Literature Review

This chapter reviewed current research, industry practices, and available technologies related to buyer engagement, cost transparency, and BIM integration in residential construction, with particular attention to staged investment models. The review began by examining how BIM improves design communication, enabling clear visualisation, linking design to schedule and cost data, and reducing errors caused by misinterpretation of 2D plans (Puķīte and Geipele, 2015; Eadie et al., 2015). While these capabilities are well established in professional workflows, the review found that they are rarely extended to buyers in a usable form.

The discussion on buyer interaction highlighted the potential benefits of structured, constraint-based customisation, such as increased buyer satisfaction and reduced post-construction changes (Zainon et al., 2020). However, in practice, buyer choices are often collected through fragmented processes — paper forms, emails, and spreadsheets which increase the risk of error and slow down decision-making. Digital configurators have improved visual engagement, but most operate outside the live BIM environment, requiring manual re-entry of information into the professional model.

Cost transparency emerged as another critical factor, particularly in staged investment projects where trust between buyers and developers is essential. While 5D BIM enables real-time cost updates linked to model changes (Infrastructures, 2018), these capabilities are typically used only by project teams. Buyers continue to receive filtered summaries rather than live, model-based pricing, limiting their ability to make fully informed decisions.

The review also examined the unique communication challenges of staged investment models, where payments are tied to milestone completion (Al Harthy et al., 2020). Current methods for milestone verification rely heavily on static reports and photographs, leaving room for disagreement over whether a stage has been completed. Integrating visual verification with milestone definitions inside a BIM environment could address this gap, but existing buyer-facing tools rarely offer this capability.

Immersive interfaces such as VR, AR, and web-based 3D platforms have been shown to improve buyer understanding and emotional engagement (Old House New Home, 2020). However, most are disconnected from the professional BIM model, which means changes made in these environments are not automatically reflected in the construction workflow. Likewise, Common Data Environments (CDEs) are central to professional BIM coordination but underutilised in buyer communication. Even when buyers are granted access, the interfaces are often too technical, and updates are not automated (Digitalization and Automation in Construction, 2021).

A comparative analysis of existing tools revealed a clear gap in the market. Consumer platforms excel in ease of use but lack technical integration, while professional platforms maintain data integrity but are difficult for buyers to navigate. No current solution offers a single environment that combines accessibility, technical accuracy, real-time cost and schedule feedback, constraint-based editing, and CDE integration for milestone verification.

From this review, the research gap becomes clear: there is a need for a buyer-facing BIM platform that merges the usability of consumer tools with the data integrity and live integration of professional systems. The next chapter outlines the methodology for developing and testing such a platform. It will detail the system architecture, data integration strategy, and evaluation process designed to assess its impact on communication, transparency, and trust in staged investment residential projects.

3 METHEDOLGY

3.1 Introduction

The methodology responds to a practical problem identified in the previous chapters. The buyers rarely interact with the live project model and instead receive static views that conceal quantity, cost, and buildability information, which limits their ability to make informed decisions in staged investment projects. The project teams, on the other hand, work with detailed BIM data that is not translated for client use in staged investment settings. The chapter therefore sets out a process that carries trustworthy BIM information into a buyer interface, allows controlled choices on non-structural elements, and returns those choices to the project environment without loss of meaning or cost traceability.

The methodology developed for this study translates the conceptual understanding gained from the literature review into a structured and practical workflow. Its purpose is to show how Building Information Modelling can be adapted into a buyer-facing platform that allows for guided customisation and immediate cost feedback, without losing the technical accuracy required in professional construction workflows. The approach is shaped by the same challenges identified earlier, particularly the difficulty buyers face in visualising designs, the lack of direct interaction with BIM data, and the uncertainty that surrounds staged investment projects.

In many residential developments, buyers encounter plans and static images that only partially represent the home they are committing to. Even in projects where BIM is used internally, the benefits often do not reach the buyer in a way that supports informed decision-making. The result is a gap between the design process and the client experience. This methodology addresses that gap by proposing a multi-stage process where data flows from professional BIM tools into an interface designed specifically for non-technical users yet still preserves the semantic and geometric detail necessary for reintegration into the BIM model.

The chapter begins by describing the overall research design and the reasoning behind a prototype-driven approach. It then outlines the architecture of the proposed system, followed by a step-by-step explanation of the workflow from model creation to buyer interaction and final data export. The methodology also details the role of classification systems, the selection of tools and technologies, and the process for validating the approach. In doing so, it sets out a pathway for turning theoretical benefits into a working system that can be tested in the context of residential projects using staged investment models.

3.2 Research Methodology

The methodology for this study was designed to ensure that the proposed solution would be both technically workable and useful in real construction practice. The research centred on creating and testing a buyer-facing BIM platform that links residential design customisation with dependable cost data, while still fitting within the professional workflows used in staged investment projects. To achieve this, the approach combined the development of a prototype with its application in a case study that mirrors the conditions of an actual project.

A case study method was chosen because it allows new tools to be tested in settings that closely reflect their intended use, a well-established strategy in construction research (Yin, 2018). The chosen case was a fully detailed apartment unit extracted from a larger residential building model. This model contained complete material specifications, layered assemblies, and standardised components, making it suitable for testing realistic construction conditions and buyer-driven modifications (Eastman et al., 2018).

The study also drew on elements of design science research, where artefacts are developed, tested, and refined in cycles. This ensured that the prototype evolved through repeated evaluation and improvement rather than being judged in a single attempt (Peffers et al., 2007). The result was not only a theoretical framework but a functioning system that could be measured for both technical and practical performance.

Professional feedback formed another part of the process. BIM managers, architects, and cost estimators were invited to comment on the usability of the interface, the clarity of cost updates, and the suitability of the applied constraints. Their involvement reflects wider evidence that engaging stakeholders is a key factor in the successful adoption of digital systems in construction projects (Jergeas, 2009).

By combining technical testing, iterative refinement, and professional validation, the methodology balanced reliability of function with alignment to industry expectations.

3.2.1 Research Objectives and Methodology Steps

This research is organised around five objectives, each linked to specific methodological steps to make sure the approach is both technically sound and relevant in practice.

Objective 1 – Platform development for controlled customisation
The first goal was to build a buyer-facing BIM platform that allows controlled customisation within residential projects. A detailed Revit model was prepared in which non-structural elements could be edited while structural parts remained fixed. Classification codes were embedded into all relevant

elements, and the model was then exported to IFC and converted into GLTF for use in a web-based interface. In this way, buyers were able to interact with the model within clear design boundaries.

Objective 2 – Linking design changes to transparent cost data
The second goal focused on creating a direct connection between buyer changes and their cost implications. A unit-rate cost database was linked to the classification codes in the model. Any change made by the buyer, such as altering materials or configurations, triggered an automated recalculation of cost, which appeared instantly on screen. This gave buyers an immediate and reliable view of how their decisions affected overall cost.

Objective 3 – Interoperability with professional BIM workflows
The third goal was to keep buyer modifications consistent with professional BIM workflows, especially in the context of staged investment projects. By using the IFC standard for data exchange, editable elements were linked to project milestones. This made it possible to reintegrate approved changes into the Common Data Environment (CDE) without losing information, allowing for milestone verification and accurate tracking of staged payments.

Objective 4 – Case study demonstration
The fourth goal was to demonstrate the platform using a realistic case study. A fully detailed apartment unit was taken from a larger residential building model and used as the testbed. This provided a practical environment in which buyer interactions, such as finish changes or partition adjustments, could be simulated under real construction conditions.

Objective 5 – Performance evaluation
The final goal was to assess the platform from both technical and user perspectives. On the technical side, the evaluation checked the accuracy of cost calculations, whether IFC properties were preserved during file conversions, and how responsive the interface was. On the user side, feedback was sought from BIM managers, architects, and cost estimators to judge the usability of the system, the clarity of cost updates, and the effectiveness of the constraint logic. Combining these two types of evaluation ensured that the platform was tested not only for precision but also for practical usefulness.

3.3 Research Design

The research design combined prototype development with a case study demonstration so that the buyer-facing BIM platform could be tested under conditions similar to those of an actual residential project. This approach made it possible to examine not only the technical performance of the prototype but also how well it fitted into professional workflows.

The central aim of the design was to create a prototype that connected design customisation with cost estimation and reintegration into the Common Data Environment (CDE). The intention was to move beyond abstract discussion and develop a working solution that could interact with recognised BIM standards, classification systems, and cost management practices. The design process was guided by OpenBIM principles, which emphasise interoperability and consistent information exchange across different platforms (buildingSMART International, 2020; ISO, 2018).

For the case study, an apartment unit was extracted from a fully detailed residential building model. The model included the necessary architectural and structural detail to distinguish between editable and fixed elements, making it suitable for simulating real construction conditions. Similar studies in residential settings have shown that this level of detail provides a solid basis for assessing BIM applications in design communication and cost transparency (Eastman et al., 2018; Gohatre et al., 2024).

This setup allowed the study to test how buyers interact with design options, how the platform produces instant cost updates, and how those updates can be integrated back into professional workflows. Previous research shows that when BIM tools are trialled in realistic project environments, they give clearer evidence of how design and cost choices shape project outcomes (Al-Roumi & Al-Sabah, 2024).

3.4 Workflow Breakdown

The workflow developed for this study follows a clear sequence that connects model preparation, data conversion, interactive modification, cost calculation, and reintegration into the Common Data Environment. Each stage was designed to keep information consistent so that both buyers and professionals could rely on the outputs.

The process started with preparing the building model in Revit, from which a single apartment unit was extracted for use as the case study. This approach ensured that the unit contained the same level of detail as the full building while remaining manageable for testing. Other BIM studies have used similar methods, taking detailed units as testbeds to validate approaches at a practical scale (Eastman et al., 2018).

Next, the model was exported into the Industry Foundation Classes (IFC) format. IFC is an open standard that allows data to move across platforms without major loss of information (buildingSMART International, 2020). The exported file was then converted into GLTF format for the web-based interface, which provides fast rendering and smooth interaction in a browser environment.

In the buyer-facing interface, users could view the apartment, adjust finishes or other non-structural elements, and immediately see the cost consequences of their choices. Each editable element was tied to classification codes that connected it to cost data in the background. This mirrors practices described in 5D BIM research, which highlight the importance of linking design decisions with dependable cost information (Wang & Tung, 2023).

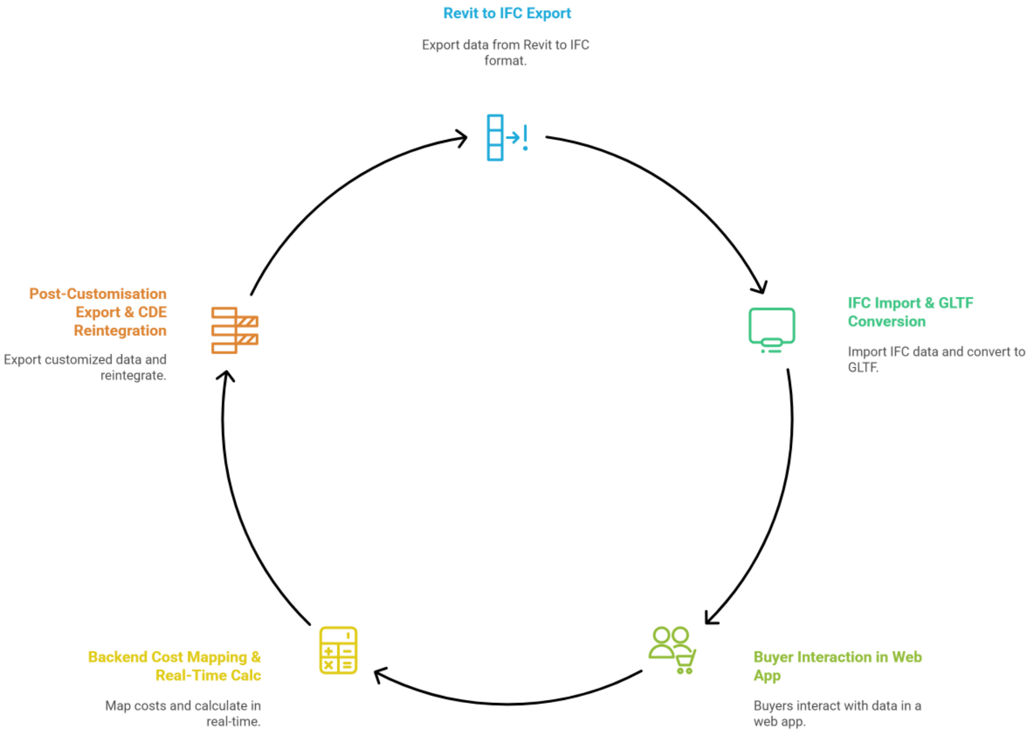


Figure 11- Workflow

The final stage of the workflow involves reintegration. At this point, the buyer’s design choices are linked back to the BIM model or recorded in an Excel sheet through the use of classification codes and then stored within the Common Data Environment. These updates feed directly into the staged investment model, where they adjust the instalment schedule. In this way, buyer-driven changes stay aligned with the overall building information and remain accessible to the wider project team, consistent with ISO information management standards (ISO, 2018).

3.4.1 Step 1 – Revit to IFC Export

The workflow begins in Autodesk Revit, where the architectural model of the residential unit is developed with careful attention to both geometric accuracy and embedded information. Each building element is modelled as it would be constructed on site, so the attached data remains meaningful throughout the process. A partition wall for a bathroom is represented as three layers. Plaster is applied on one side, a masonry core sits in the middle, and tiles are placed on the opposite face.

The same principle is applied to other elements. Windows are defined with frame type, glazing specification, and opening method. Floors are modelled with multiple layers such as a structural slab, a screed layer, and the chosen floor finish. By treating each element as a complete assembly, the model retains its technical depth and its potential for accurate cost mapping once it is transferred to other platforms.

Classification codes from systems such as OmniClass or Uniclass are assigned to every element. These codes link the digital representation of the wall, window, or floor to the corresponding cost items in the estimation database. Where available, unit prices are embedded within the element properties using Revit parameters. This ensures that cost-related data travels with the model and remains accessible in later stages.

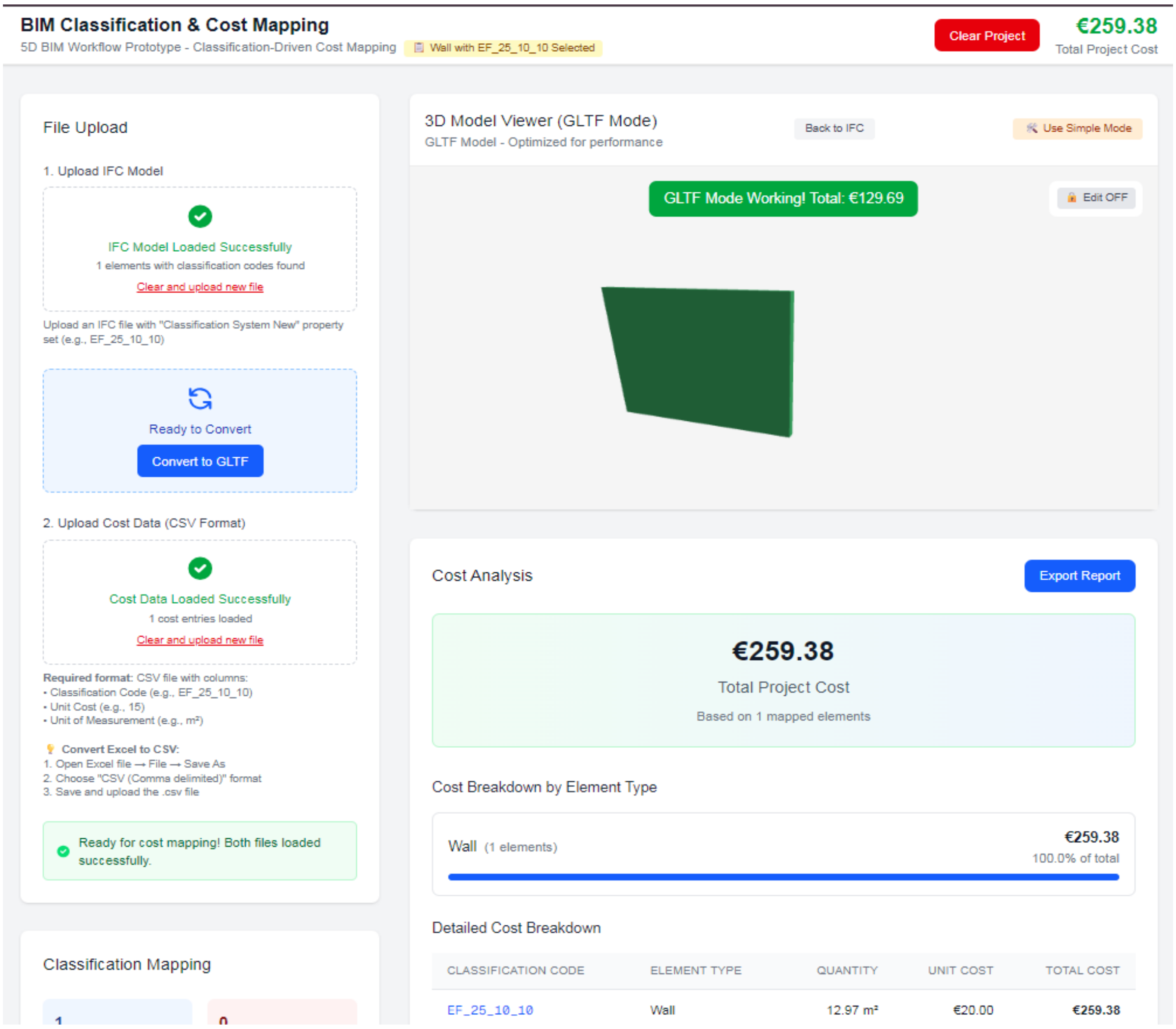
When the model is exported to the Industry Foundation Classes format, both the geometry and the metadata are preserved. IFC has been selected for its ability to store classification codes, quantities, and property sets alongside model geometry in an open and standardised format. This makes it possible to maintain the relationship between design changes and cost updates in the buyer interface. The exported IFC file becomes the foundation for all subsequent stages of the workflow.

3.4.2 Step 2 – IFC Import and Conversion to GLTF

Once the residential unit has been modelled and exported from Revit as an IFC file, the next step is to bring this data into the buyer-facing application. The process begins with parsing the IFC file using an open-source parser such as IFC.js. The parser reads both the geometry and the metadata of each element, ensuring that the information attached in Revit is still intact.

After parsing, the IFC model is converted into the GLTF format, which is optimised for efficient rendering in a web browser. GLTF is well suited for interactive visualisation because it allows the 3D model to load quickly without sacrificing detail. During this conversion, the classification codes, material definitions, and unit cost parameters remain linked to each element. When the buyer later clicks on the wall, the system recognises it. which is associated with its cost and classification code. The same applies to windows and floors, where the technical details remain preserved for accurate cost mapping.

This stage of the workflow is critical because it represents the bridge between professional BIM environments and a lightweight web-based visualisation platform. If metadata were lost during conversion, the buyer interface would display only geometry with no connection to the cost or classification logic that drives the system. By ensuring that every wall, window, and floor retains its metadata, the model remains semantically rich even in a simplified 3D format.



BIM Classification & Cost Mapping
5D BIM Workflow Prototype - Classification-Driven Cost Mapping
Wall with EF_25_10_10 Selected
€259.38
Total Project Cost

File Upload

1. Upload IFC Model
IFC Model Loaded Successfully
1 elements with classification codes found
Upload an IFC file with "Classification System New" property set (e.g., EF_25_10_10)

Ready to Convert

2. Upload Cost Data (CSV Format)
Cost Data Loaded Successfully
1 cost entries loaded

Required format: CSV file with columns:
- Classification Code (e.g., EF_25_10_10)
- Unit Cost (e.g., 15)
- Unit of Measurement (e.g., m²)

Convert Excel to CSV:
1. Open Excel file → File → Save As
2. Choose "CSV (Comma delimited)" format
3. Save and upload the .csv file

Ready for cost mapping! Both files loaded successfully.

Classification Mapping
1
0

3D Model Viewer (GLTF Mode)
GLTF Model - Optimized for performance

GLTF Mode Working! Total: €129.69

Cost Analysis

€259.38
Total Project Cost
Based on 1 mapped elements

Cost Breakdown by Element Type

Wall (1 elements) — **€259.38**, 100.0% of total

Detailed Cost Breakdown

CLASSIFICATION CODE	ELEMENT TYPE	QUANTITY	UNIT COST	TOTAL COST
EF_25_10_10	Wall	12.97 m²	€20.00	**€259.38**

Figure 12- IFC to GLTF conversion process

3.4.3 Step 3 – Buyer Interaction in Web Application

Once the model is converted into GLTF, it is presented to buyers through a web-based graphical interface. The interface is intended to be straightforward for non-technical users while still containing enough detail to provide reliable cost feedback. Interaction is deliberately limited to architectural elements that can be changed without compromising structural safety or regulatory compliance.

Buyers navigate the 3D model with simple orbit, pan, and zoom controls. For example, clicking on a bathroom wall highlights it and opens a side panel showing its three-layer assembly of plaster, masonry, and tile. The buyer can switch between different plaster or tile finishes, while the masonry core remains locked. A similar process applies to windows, where the system displays available frame materials, glazing types, or opening styles. For floors, buyers may choose finishes such as ceramic tiles, laminate, or vinyl, but the structural slab and screed stay fixed.

Every modification triggers an automatic cost update. The application sends the element's classification code to the backend, retrieves the unit rate from the cost database, multiplies it by the element's measured quantity, and applies any wastage factor. The new total is then displayed immediately in the interface, allowing buyers to see the financial impact of their choices in real time.

The interface also uses visual cues to make the process clear. Elements that cannot be altered are shaded or marked with a lock icon, so buyers know which components are fixed. Materials that fall outside the project scope are either removed from the menu or labelled clearly as "not available." The aim is to balance creative freedom with technical feasibility, making sure that all selected options remain buildable and consistent with project standards.

By combining intuitive visual interaction with instant cost updates, this stage bridges the gap between design understanding and cost awareness. It shifts the buyer's role from a passive recipient of information to an active participant in the design process, while keeping every decision aligned with the constraints set earlier in the workflow.

3.4.4 Step 4 – Backend Cost Mapping and Real-Time Calculation

The backend system forms the computational core of the workflow, translating buyer selections into accurate cost outputs. It runs as an independent service connected to the web interface, ensuring that pricing data is handled in a structured and secure way. By linking the classification system in the model with the cost database, the backend allows calculations to be carried out consistently and repeated with accuracy.

When a buyer modifies an element in the interface, the system captures its classification code together with its quantity data. Quantities are derived automatically from the model geometry: surface area is used for finishes such as plaster or tiles, linear measurements for components like skirting boards, and volumes where appropriate. For the multilayer bathroom wall, the backend calculates the tile area on one side, the plaster area on the other, and keeps the masonry core fixed. In the case of windows, the calculation considers both the frame perimeter and glazing area, while for floors it measures the total surface finish.

The system then matches these quantities with the relevant unit price in the cost database. This database is stored externally, in either JSON or Excel format, so that prices can be updated without regenerating the IFC model. Each unit price is tied to a classification code and may also carry additional details such as supplier information, lead times, or maintenance costs. The backend multiplies the quantity by the unit price and applies a wastage factor to account for on-site material losses, cutting, and handling.

Once the element cost has been calculated, the backend sends the updated value back to the interface in real time. If several edits have been made, the results are aggregated so that buyers can see both the cost of individual elements and the total cost of all their choices. This allows each decision to be understood not only in isolation but also in the wider financial context of the unit.

The backend also records every change, including the time of update, the selected materials, and the resulting prices. This creates a traceable history of design and cost decisions, giving the project team a reliable basis for procurement and schedule alignment. By structuring the backend as a modular, data-driven service, the workflow ensures that cost calculations remain consistent, transparent, and easy to maintain throughout the project lifecycle.

3.4.5 Step 5 – Post-Customisation Export and BIM/CDE Reintegration

The final stage of the workflow transfers buyer-driven modifications back into the main project environment, ensuring that all parties continue to work from a single, reliable source of information. This step is essential for keeping design intent, cost data, and construction documentation aligned.

When the buyer finishes the customisation process, the web application generates a structured record of all changes. This record includes material substitutions, revised classification codes, and the recalculated costs. Two export methods can then be used, depending on project requirements:

1. **Full IFC regeneration.** In the current prototype, the interactive model operates in GLTF format and does not automatically create an updated IFC file. In practice, professionals would need to update or regenerate the IFC manually based on the buyer's selections. At the same time, the linked 5D Excel sheet is refreshed automatically so that staged investment costs remain accurate and tied to the new design.

2. **Delta export.** Instead of rebuilding the entire model, the system can generate a smaller "change file" or update the 5D Excel sheet with only the modified elements and attributes. This method is particularly useful in large residential developments with many units, since it avoids processing the whole dataset. Crucially, delta exports update the staged investment model immediately, as installment amounts are recalculated from the revised unit costs. For instance, if a buyer upgrades a wall from plaster to ceramic tiles, the added cost is distributed into the remaining installment schedule, giving both buyer and developer instant clarity about the financial adjustment.

Both approaches follow the same classification structure, which keeps cost mapping, procurement tasks, and construction sequencing consistent. Each modification, such as a finish replacement, is logged to provide a clear audit trail of buyer decisions.

Once the export is complete, the updated model or change file is uploaded into the project's Common Data Environment (CDE), such as Autodesk Construction Cloud or Dalux. This reintegration ensures that designers, estimators, contractors, and procurement managers all work with the same validated dataset. In this way, buyer selections flow smoothly from the web interface into project documentation, cost planning, and staged payment schedules.

3.5 Role of Classification Systems

A clear classification system is central to linking the digital model of building elements with their cost, procurement, and construction data. In the proposed methodology, classification codes act as unique identifiers, ensuring that each element is consistently tied to its unit price, supplier details, and material properties. This link is essential; without it, changes made through the buyer-facing interface could not be reliably converted into cost updates or procurement records.

International systems such as Uniclass, OmniClass, and MasterFormat provide structured frameworks for categorising elements by function, material, or location. In this workflow, classification codes are embedded into the IFC model at the authoring stage in Revit. By integrating codes early, the process ensures that even if a buyer modifies an element later, its classification code remains the main reference for cost mapping and data retrieval (Eastman et al., 2018).

The workflow supports two main scenarios during buyer interaction. The first is when a material category stays the same but the quality or grade is changed. In this case, the classification code remains constant, while attributes such as finish grade or material type are updated. For example, a bathroom wall finished in standard gypsum plaster could be upgraded to lime plaster. The classification code for "plaster wall finish" would stay the same, but the cost database would return a new unit price by combining the unchanged code with the revised attributes.

The second scenario occurs when a buyer replaces one material with another from a different category, which requires a new classification code. For instance, substituting plaster with ceramic tiles changes the code from Pr_35_31_54_62 – Plaster wall finish to Pr_35_31_67_15 – Ceramic tile wall finish. This update directs the cost database to reference the new category and its associated price and attributes, ensuring that the cost calculation is accurate (Pishdad & Onungwa, 2024).

By handling attribute updates within the same classification and full reclassification when categories change, the system can support a wide range of buyer modifications while preserving consistency and traceability. This layered approach allows quality upgrades to be processed efficiently without altering the underlying structure, while category changes trigger the necessary database updates to maintain reliable cost and procurement data.

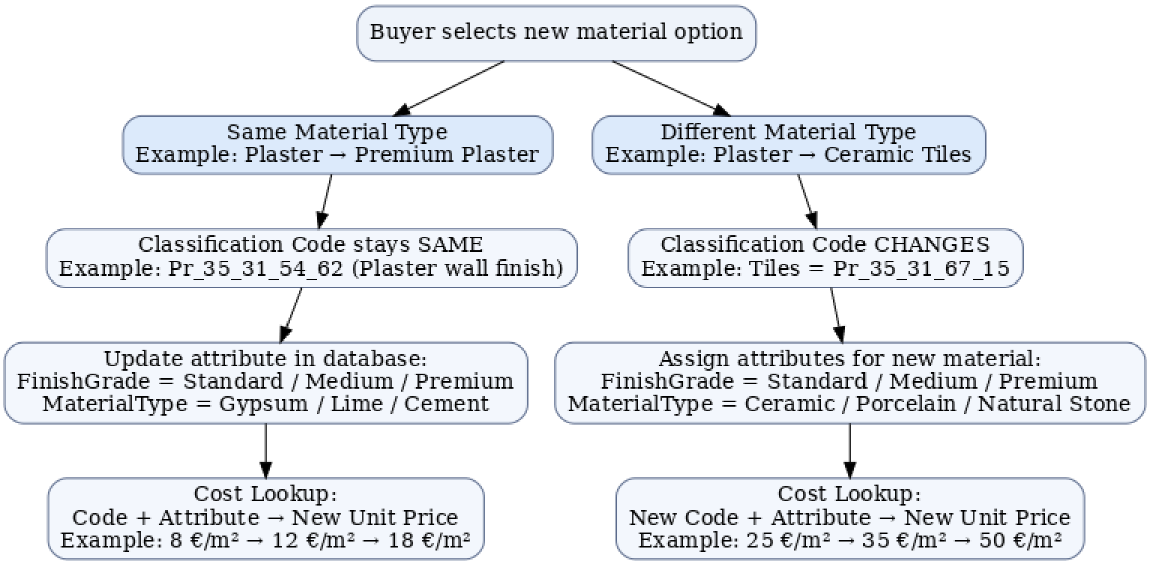


Figure 13- Material changes with classification system logic

This image illustrates how the process works, showing the way classification codes and attributes function together to handle both upgrades within the same category and replacements across categories. In this way, the methodology links the buyer interface with the cost calculation backend and the BIM/CDE environment, ensuring that any design change remains technically consistent and financially transparent.

3.6 Tools and Technologies

The methodology relies on a mix of BIM authoring tools, open data standards, web-based visualisation frameworks, and structured cost databases. Each tool plays a distinct role within the workflow, while the overall design ensures interoperability and scalability.

Autodesk Revit was used to create the residential unit model. Its parametric modelling features allowed precise definition of elements, including geometry, classification codes, and material attributes. Revit supports the export of Industry Foundation Classes (IFC) files, so data such as classifications, quantities, and unit prices can move to other platforms without loss. It also supports multilayer assemblies—for example, a bathroom wall containing plaster, masonry, and tile finish—which is essential for technical accuracy in later cost calculations.

Data exchange with IFC. IFC served as the neutral file format for transferring the model from Revit to the buyer-facing platform. By carrying both geometry and metadata, IFC kept classification codes, material properties, and cost parameters linked to their elements. Its use also ensured that the system remained vendor-neutral and consistent with openBIM principles (buildingSMART International, 2020).

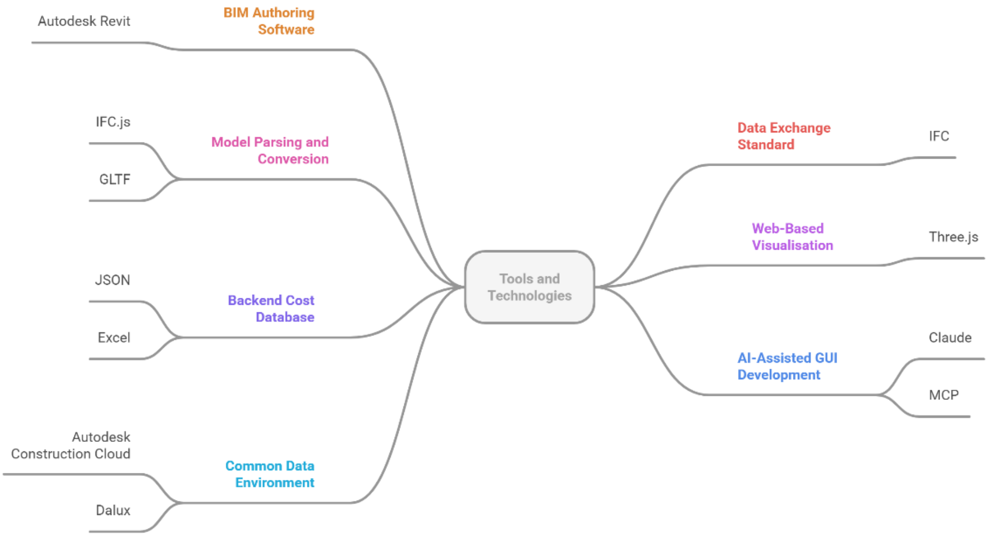


Figure 14- Tools & technology

Parsing and conversion with IFC.js and GLTF. In the web environment, IFC.js an open-source JavaScript library was used to parse the model and extract both geometry and metadata. The parsed file was then converted to GLTF for efficient rendering in a browser. GLTF's lightweight structure provided quick loading times while still preserving the richness of the model data.

Web-based visualisation using Three.js. Three.js acted as the rendering engine for displaying the 3D model. It enabled intuitive navigation and element selection, while custom scripts ensured that buyers could only edit predefined attributes. This prevented changes that might compromise structural integrity or regulatory compliance.

Backend cost database in JSON/Excel. Unit costs were stored externally in JSON or Excel files. Each price was linked to a classification code and, where relevant, attributes such as supplier, lead time, or maintenance requirements. Storing data externally allowed quick updates without modifying the model, making it possible to respond to changing market conditions.

AI-assisted GUI development. The buyer interface was created through a combination of manual coding and AI-assisted prototyping with Claude and the Model Context Protocol (MCP). This hybrid approach made it possible to develop interactive features quickly, including material selection panels, real-time cost displays, and constraint-based editing tools. Screenshots of the prototype will be included in the final dissertation to illustrate user interaction.

Common Data Environment (CDE) platforms. Tools such as Autodesk Construction Cloud and Dalux were used for reintegration. They provided version control, access permissions, and centralised documentation, ensuring that all stakeholders worked from the same validated dataset.

Together, these tools created a workflow that is both technically robust and practical. Open standards such as IFC supported interoperability, while web frameworks like Three.js and IFC.js provided accessibility for non-technical users. The structured cost database, supported by classification systems, guaranteed transparent and consistent cost calculations.

Data Sources and Data Collection

The data for this research came from both technical and professional sources. On the technical side, the case study model was developed in Autodesk Revit in line with the RIBA Plan of Work. This approach ensured that the design carried the right level of detail for testing, including architectural layouts, structural elements, and layered assemblies. The model therefore provided a sound basis for analysing design changes and their cost implications (RIBA, 2020).

The model was exported to the Industry Foundation Classes (IFC) format to preserve consistency across platforms and support interoperability. IFC defines the structure for geometry, quantities, classifications, and property sets, which are essential in openBIM workflows (buildingSMART International, 2020). Exporting to IFC meant the case study could be imported into the web-based platform without significant loss of information.

On the professional side, input was gathered from BIM managers, architects, and cost estimators. They were asked to comment on the clarity of cost updates, the usability of the buyer-facing interface, and the suitability of the applied constraints. Earlier research shows that this type of stakeholder involvement plays a key role in construction investment processes, as collaborative input strengthens both design and cost-related decisions (Jergeas, 2009).

In practice, the data collection process therefore brought together structured digital information embedded in the BIM model with insights from experienced professionals. This combination ensured that the platform was assessed not only for technical accuracy but also for its relevance to industry practice.

3.7 Validation and Evaluation

Validation and evaluation in this study combined technical testing with professional feedback. The purpose was to confirm that the prototype worked reliably in terms of cost calculation, data integrity, and responsiveness, while also being judged as practical and relevant by professionals.

The first stage of validation focused on technical performance. Tests were run to check that the IFC-to-GLTF conversion retained key information such as classifications and material properties. This step was important, as data loss during file conversion has often been highlighted as a challenge in openBIM workflows (buildingSMART International, 2020). The accuracy of automated cost calculations was also examined by comparing the platform's results with manual estimates taken from the same model data, following approaches used in earlier 5D BIM studies (Pishdad & Onungwa, 2024).

The second stage centred on professional evaluation. BIM managers, architects, and cost estimators were asked to review the usability of the interface, the clarity of cost updates, and whether the applied constraints were reasonable. Prior studies show that this type of qualitative feedback is vital when introducing digital tools into construction workflows (Jergeas, 2009).

Finally, the platform was assessed on its ability to reintegrate design changes back into the Common Data Environment without breaking the links between model elements and cost data. This step was critical, since integration into the broader project environment is what determines whether a prototype can realistically be adopted in practice (Eastman et al., 2018).

3.8 Constraints

The methodology was developed within a set of defined constraints that outline the operational boundaries of the system. These limits were not treated as shortcomings but as deliberate choices, introduced either to keep the prototype technically feasible or to maintain focus on the research objectives. By setting these boundaries clearly, the workflow avoided unnecessary complexity and ensured that the prototype could be built, tested, and evaluated within the available time and resources.

One important constraint is that the buyer-facing interface allows modifications only to non-structural elements. Structural components such as load-bearing walls, beams, and columns remain locked in the model in order to preserve safety and design integrity. Editable elements are limited to finishes and secondary components, including the multilayer bathroom wall, windows, and floor coverings. This ensures that customisation does not compromise the technical stability of the project.

A second constraint relates to the material options offered for each editable element. Rather than leaving the selection open-ended, the system provides predefined choices grouped into standard, medium, and premium categories. This keeps cost variability under control, supports procurement planning, and ensures that all options are consistent with the project's schedule and technical requirements. For example, plaster finishes may be limited to gypsum, lime, or cement types, while tiles may be restricted to ceramic, porcelain, or natural stone.

The prototype itself was further limited in scope to a single residential unit extracted from a larger apartment building. This allowed detailed testing of the workflow without the additional complexity of coordinating multiple units. Although the same methodology could be scaled to entire buildings or residential developments, the prototype concentrated on demonstrating core functionality at the unit level.

Another constraint concerns technical interoperability. The system was designed to operate exclusively with the Industry Foundation Classes (IFC) format as input. This ensured compliance with openBIM principles and preserved both geometry and semantic data across different platforms. While other formats could in theory be supported, limiting the workflow to IFC provided a consistent and standardised base.

By setting these constraints, the study created a controlled environment in which both technical performance and user experience could be reliably assessed. The boundaries were intentionally narrow to demonstrate the concept effectively, while still leaving scope for extension in future research or commercial use.

3.9 Summary

This chapter has presented the methodological framework developed to design and test a buyer-facing BIM workflow for residential projects that follow staged investment models. The approach combined BIM authoring in Autodesk Revit, data exchange through IFC, model parsing and conversion with IFC.js and GLTF, and web-based 3D visualisation using Three.js. A structured cost database, linked to classification codes and material attributes, provided real-time pricing feedback for buyer-led modifications.

The workflow began with the preparation of a detailed residential unit in Revit and moved through export, web interaction, backend cost calculation, and reintegration into the Common Data Environment. Each stage was illustrated with practical examples, such as altering a multilayer bathroom wall, adjusting a window assembly, or changing floor finishes, so that both technical and functional aspects of the system were demonstrated in practice.

Integrating classification systems into the workflow created a reliable link between design elements and cost data. This supported both material upgrades within the same category and substitutions across categories, ensuring precise cost mapping and consistency throughout design, procurement, and construction. The tools and technologies were chosen with an emphasis on interoperability, open standards, and scalability, while AI-assisted development accelerated interface prototyping without reducing technical control.

The chapter also set out the boundaries of the research through a defined set of constraints. These ensured that the system remained feasible and aligned with its objectives. Possible limitations—such as performance issues with complex models, reliance on cost database updates, and challenges in model reintegration were identified together with strategies to mitigate them. The validation framework was structured to measure both technical reliability and the system's value in improving buyer engagement and cost transparency.

By combining a robust BIM-to-web workflow with a carefully scoped range of buyer interactions, the methodology offers a workable way of closing the gap between design intent, cost awareness, and stakeholder participation. The following chapter will present the results of applying this methodology, assessing its performance in practice and its potential for broader use in residential construction.

4 PROTOTYPE DEVELOPMENT AND CASE STUDY

4.1 Introduction

The earlier chapters explained how the research was planned and how the workflow was designed to link BIM data, classification codes, and cost updates for staged investment. This chapter now shows how the plan was turned into a working prototype and tested in practice.

The prototype was made as a simple web-based tool where a buyer can look at a 3D model of an apartment, make changes to some parts, and directly see how the price changes. The aim of this tool is not to replace professional BIM software but to act as a bridge between the technical model and the buyer, so they can clearly understand the effect of their choices.

The development followed a step-by-step process. First, the apartment elements were exported from Revit into IFC with classification numbers. Then an Excel sheet was made with cost data mapped to these classification codes. Finally, the model was converted to a lighter format (GLTF) and connected to a web viewer, where the buyer could interact with it.

A case study was used to test this system. A flat from a residential building was selected, and one wall from this flat was chosen for testing. By changing the material or the size of this wall in the prototype, the system updated the cost instantly and showed the result to the buyer. This simple test gave proof that the idea can work in practice.

It is important to note that the prototype does not give the buyer complete freedom to design from an empty space. Buyers are non-technical, and such freedom would be overwhelming. Research shows that most buyers prefer guided customisation within an existing model rather than starting from scratch (Puķīte and Geipele, 2015; Zainon et al., 2020). For this reason, the case study begins with a ready-made 3D unit, ensuring that the buyer can focus on clear and meaningful changes instead of being lost in a blank environment.

This chapter is divided into four parts. The first part explains how the prototype was developed, the second part describes the case study, the third part presents the results from the testing, and the last part gives a short summary before moving to the discussion.

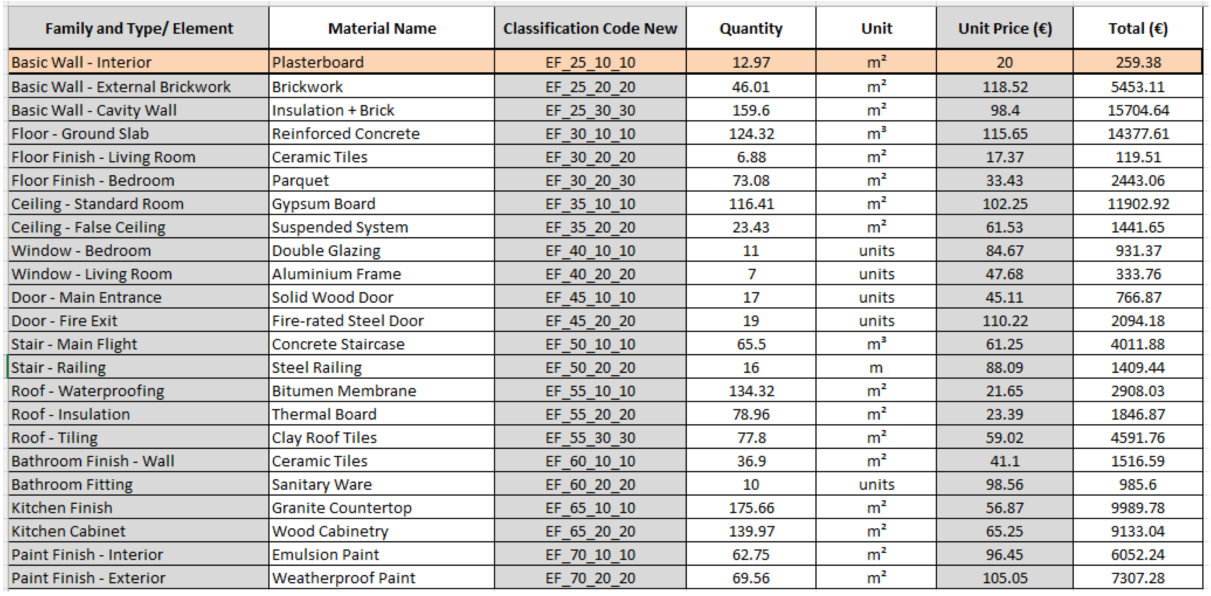
It is important to note that the demonstration screenshots show slightly different interfaces. This happened because the system was developed in separate segments. Due to the complexity of the code, it was not always possible to make all parts run together, so the initial parsing module, the buyer interface, and the testing environment each appeared with their own layouts. At several points the code became unstable, often leading to errors and corrupted files, which made it necessary to test each segment independently.

4.2 Prototype Development Process

4.2.1 System Architecture Recap

The prototype was designed on top of a standard 5D BIM process. In a normal workflow, 5D estimation is carried out for the entire building. All elements in the building are given a classification number, and each classification is connected with a unit cost. Tools such as CostX or BEXEL Manager are commonly used for this purpose. They allow quantities to be extracted directly from the BIM model and matched with cost data. The result is a detailed Excel sheet where every element of the building is listed with its code, unit of measurement, quantity, and cost. This Excel file forms the backbone of the 5D model and is usually the basis for staged investment calculations.

In this research, the case study was built by focusing on one flat unit inside a multi-storey residential building. From the complete 5D estimation of the whole building, the elements of this one unit were extracted. Each element of the unit still carried its unique classification number, which made it possible to keep it separate from similar elements in other flats in the same building. For example, a kitchen partition wall as highlighted in Figure 13 in one unit has a different identifier than the same type of wall in another unit. This distinction ensured that when a buyer makes changes in one flat, the impact is tracked correctly without mixing it with other parts of the building. A small example of the sheet is given below.



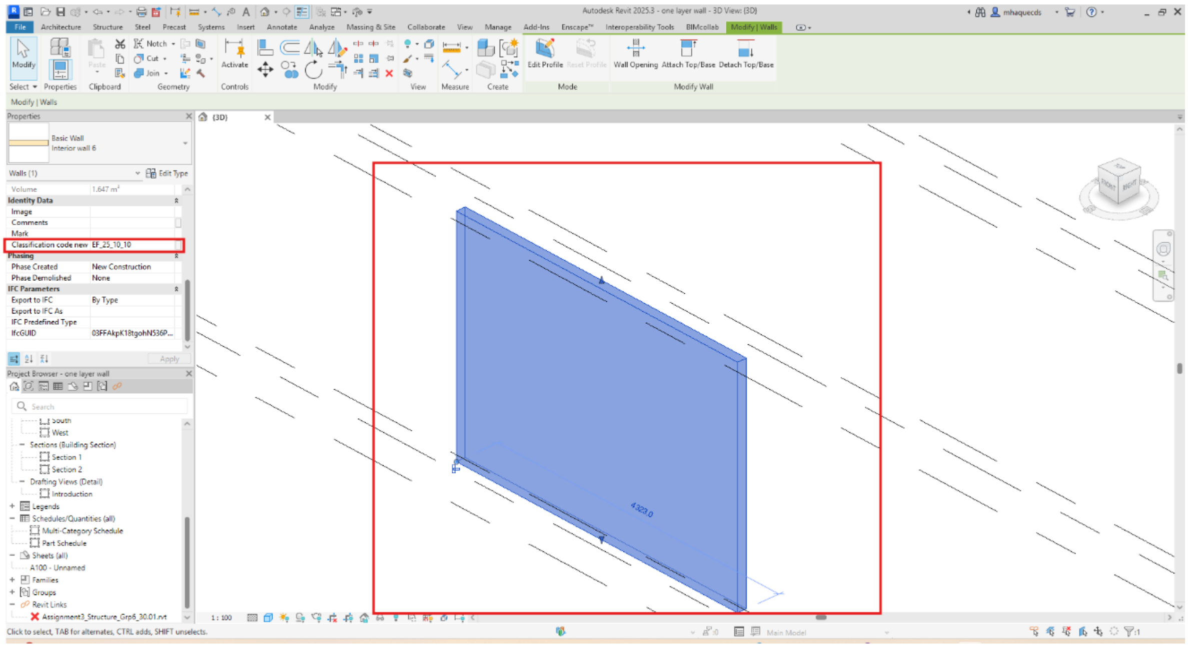
Family and Type/ Element	Material Name	Classification Code New	Quantity	Unit	Unit Price (€)	Total (€)
Basic Wall - Interior	Plasterboard	EF_25_10_10	12.97	m²	20	259.38
Basic Wall - External Brickwork	Brickwork	EF_25_20_20	46.01	m²	118.52	5453.11
Basic Wall - Cavity Wall	Insulation + Brick	EF_25_30_30	159.6	m²	98.4	15704.64
Floor - Ground Slab	Reinforced Concrete	EF_30_10_10	124.32	m³	115.65	14377.61
Floor Finish - Living Room	Ceramic Tiles	EF_30_20_20	6.88	m²	17.37	119.51
Floor Finish - Bedroom	Parquet	EF_30_20_30	73.08	m²	33.43	2443.06
Ceiling - Standard Room	Gypsum Board	EF_35_10_10	116.41	m²	102.25	11902.92
Ceiling - False Ceiling	Suspended System	EF_35_20_20	23.43	m²	61.53	1441.65
Window - Bedroom	Double Glazing	EF_40_10_10	11	units	84.67	931.37
Window - Living Room	Aluminium Frame	EF_40_20_20	7	units	47.68	333.76
Door - Main Entrance	Solid Wood Door	EF_45_10_10	17	units	45.11	766.87
Door - Fire Exit	Fire-rated Steel Door	EF_45_20_20	19	units	110.22	2094.18
Stair - Main Flight	Concrete Staircase	EF_50_10_10	65.5	m³	61.25	4011.88
Stair - Railing	Steel Railing	EF_50_20_20	16	m	88.09	1409.44
Roof - Waterproofing	Bitumen Membrane	EF_55_10_10	134.32	m²	21.65	2908.03
Roof - Insulation	Thermal Board	EF_55_20_20	78.96	m²	23.39	1846.87
Roof - Tiling	Clay Roof Tiles	EF_55_30_30	77.8	m²	59.02	4591.76
Bathroom Finish - Wall	Ceramic Tiles	EF_60_10_10	36.9	m²	41.1	1516.59
Bathroom Fitting	Sanitary Ware	EF_60_20_20	10	units	98.56	985.6
Kitchen Finish	Granite Countertop	EF_65_10_10	175.66	m²	56.87	9989.78
Kitchen Cabinet	Wood Cabinetry	EF_65_20_20	139.97	m²	65.25	9133.04
Paint Finish - Interior	Emulsion Paint	EF_70_10_10	62.75	m²	96.45	6052.24
Paint Finish - Exterior	Weatherproof Paint	EF_70_20_20	69.56	m²	105.05	7307.28

Figure 15- sheet extracted from the building for the prototype with classification

Once the unit was isolated, the prototype concentrated on a single wall inside it. This was done to simplify the testing and to show clearly how the workflow operates. The important point is that the Excel sheet used in the prototype still comes from the full building's 5D estimation, not from an isolated test file. This means that the updates from the wall are reflected inside the same data structure that controls the staged investment model. The system architecture linked three main components:

1. IFC Model from Revit – Each element exported with classification codes.

One of the elements was created in Revit and then exported in IFC format includes the most important identity that is classification number which is highlighted in Figure 16 below.



Basic Wall
Interior wall 6

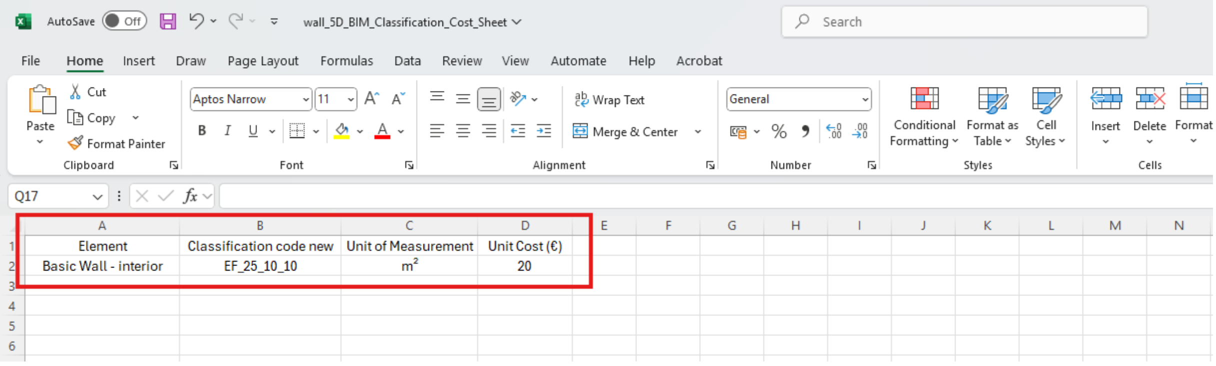
Walls (1)

Volume	1.647 m²
Identity Data	
Image	
Comments	
Mark	
Classification code new	EF_25_10_10
Phasing	
Phase Created	New Construction
Phase Demolished	None
IFC Parameters	
Export to IFC	By Type
Export to IFC As	
IFC Predefined Type	
IfcGUID	03FFAkpK18tgohN536P...

Figure 16- Model in Revit

2. 5D Excel Sheet from Full Building Estimation – Containing all classification codes, unit rates, and costs.

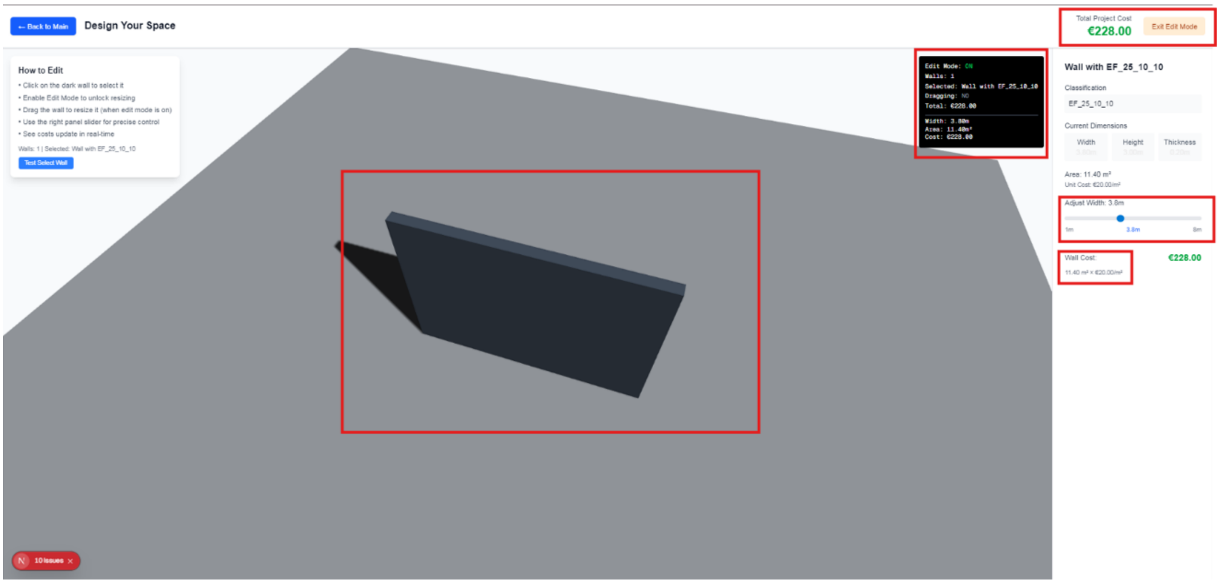
From the extensive list of building elements with various classification numbers, a single wall element was selected for testing. This is illustrated in Figure 17 below.



Element	Classification code new	Unit of Measurement	Unit Cost (€)
Basic Wall - interior	EF_25_10_10	m^2	20

Figure 17- One element details extracted from 5D list

3. Web Prototype (GLTF Viewer) – Connected to the Excel sheet, allowing buyers to change wall size or material and see the cost update in real time. Which can be clearly seen in the (Figure 15).



How to Edit
- Click on the dark wall to select it
- Enable Edit Mode to unlock resizing
- Drag the wall to resize it (when edit mode is on)
- Use the right panel slider for precise control
- See costs update in real-time

Walls: 1 | Selected: Wall with EF_25_10_10

```
Edit Mode: ON
Walls: 1
Selected: Wall with EF_25_10_10
Dragging: NO
Total: €228.00
Width: 3.80m
Area: 11.40m²
Cost: €228.00
```

Total Project Cost €228.00

Wall with EF_25_10_10

Classification: EF_25_10_10

Current Dimensions: Width, Height, Thickness

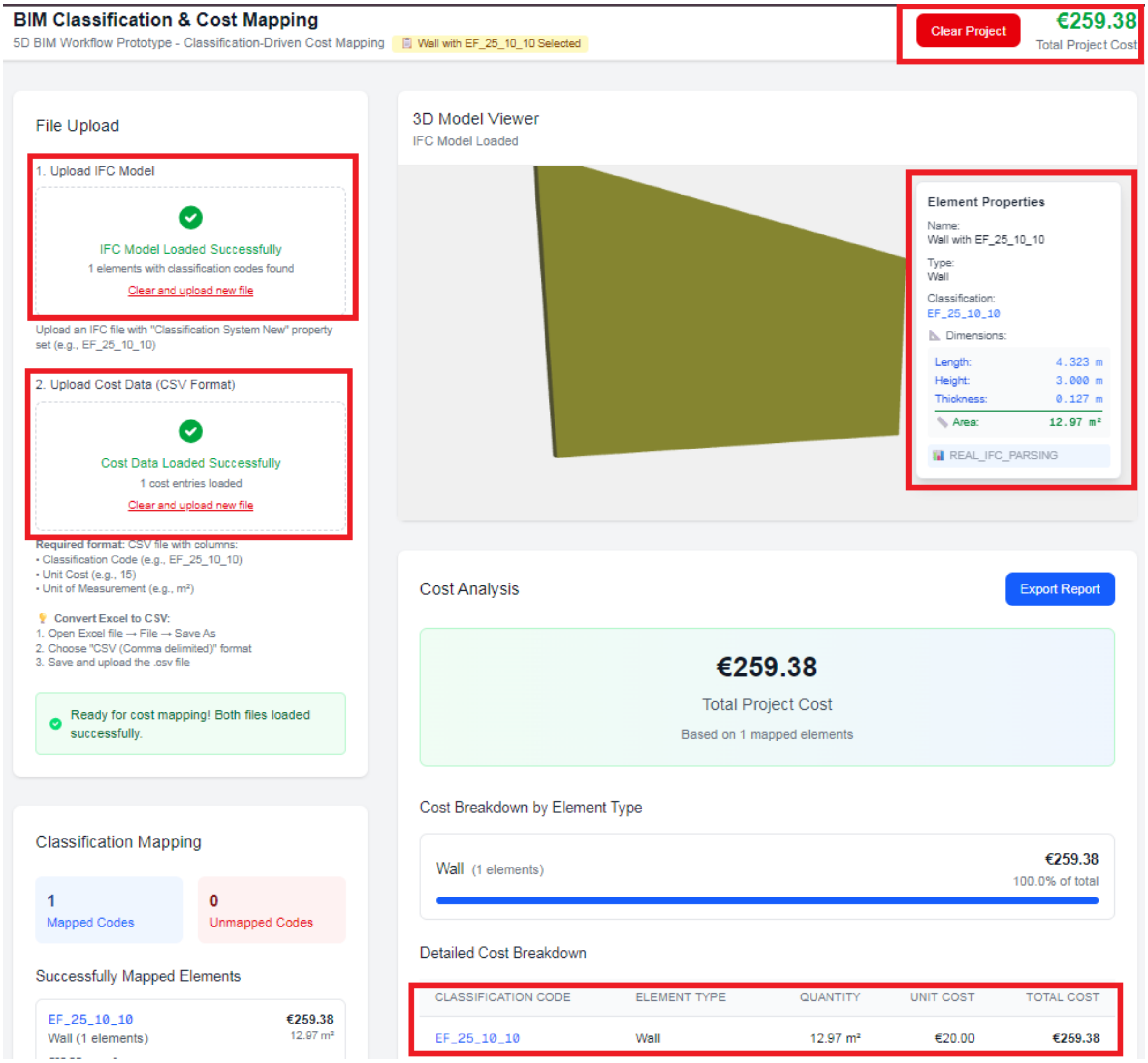
Area: 11.40 m²
Unit Cost: €20.00/m²

Adjust Width: 3.8m (1m – 3.8m – 8m)

Wall Cost: 11.40 m² × €20.00/m² €228.00

Figure 18- Customisation updates showing cost changes on screen live

The IFC file was first uploaded into the prototype, where it was read using IFC.js. At the same time, the Excel file was uploaded in CSV format. The system mapped the classification codes in the IFC with those in the Excel sheet. This mapping ensured that when the buyer edited a wall, the prototype fetched the correct unit rate from the Excel database and recalculated the cost. That can be clearly seen in the Figure 18.



BIM Classification & Cost Mapping

5D BIM Workflow Prototype - Classification-Driven Cost Mapping

Wall with EF_25_10_10 Selected

€259.38
Total Project Cost

File Upload

1. Upload IFC Model

IFC Model Loaded Successfully
1 elements with classification codes found

Upload an IFC file with "Classification System New" property set (e.g., EF_25_10_10)

2. Upload Cost Data (CSV Format)

Cost Data Loaded Successfully
1 cost entries loaded

Required format: CSV file with columns:
- Classification Code (e.g., EF_25_10_10)
- Unit Cost (e.g., 15)
- Unit of Measurement (e.g., m²)

Convert Excel to CSV:
1. Open Excel file → File → Save As
2. Choose "CSV (Comma delimited)" format
3. Save and upload the .csv file

Ready for cost mapping! Both files loaded successfully.

Classification Mapping

1 Mapped Codes

0 Unmapped Codes

Successfully Mapped Elements

EF_25_10_10 Wall (1 elements)	€259.38 12.97 m²

3D Model Viewer

IFC Model Loaded

Element Properties

Name:
Wall with EF_25_10_10

Type:
Wall

Classification:
EF_25_10_10

Dimensions:

Length:	4.323 m
Height:	3.000 m
Thickness:	0.127 m
Area:	12.97 m²

REAL_IFC_PARSING

Cost Analysis

€259.38
Total Project Cost
Based on 1 mapped elements

Cost Breakdown by Element Type

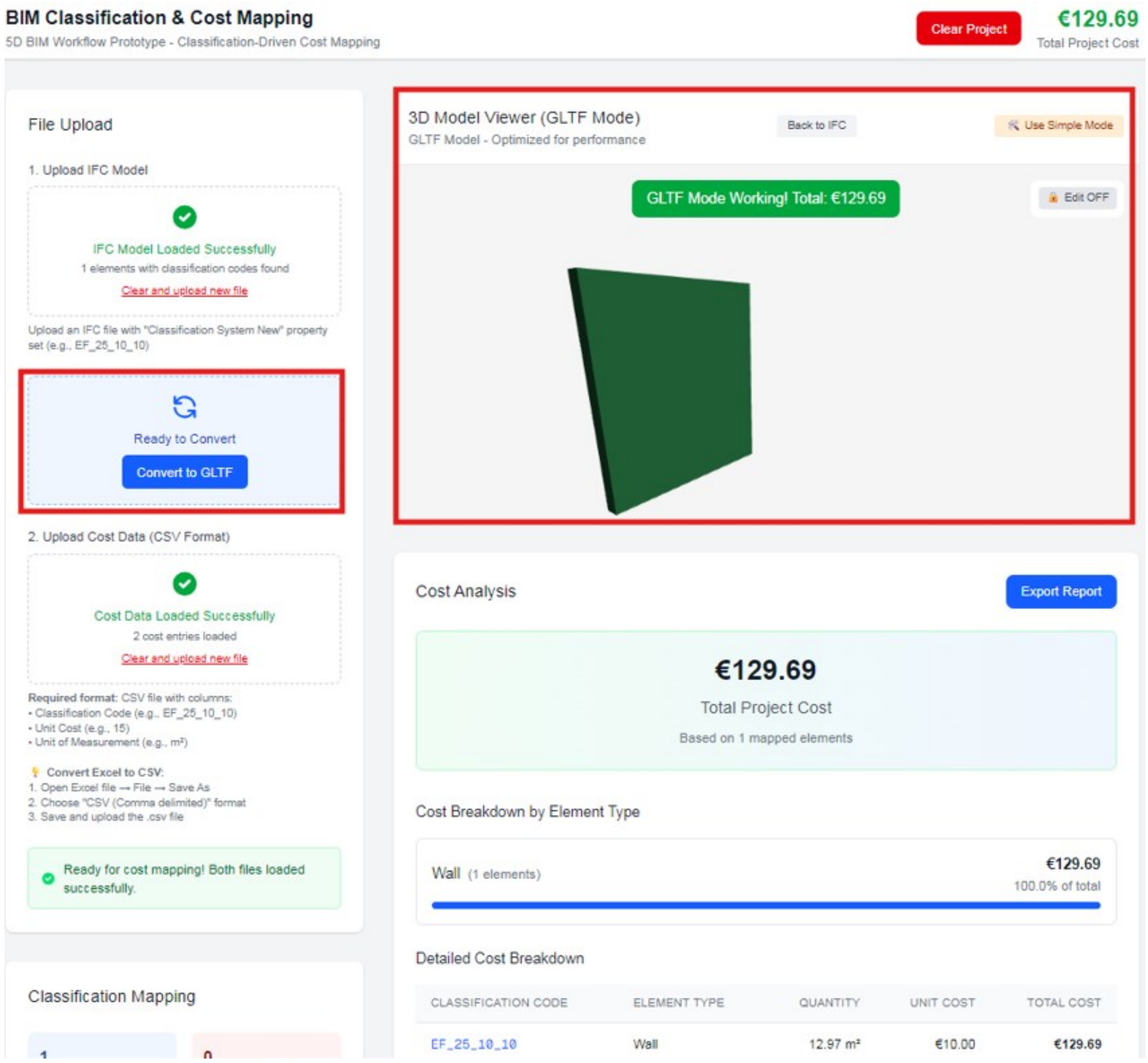
Wall (1 elements) — €259.38, 100.0% of total

Detailed Cost Breakdown

CLASSIFICATION CODE	ELEMENT TYPE	QUANTITY	UNIT COST	TOTAL COST
EF_25_10_10	Wall	12.97 m²	€20.00	**€259.38**

Figure 19- Fetching IFC & 5D data based on classification number

Finally, the IFC was converted into GLTF format. GLTF is lighter and faster to render in a web browser. The critical step was that during this conversion, the classification numbers and quantities were preserved Figure 19. This allowed the buyer to interact with the wall in the GLTF model, while the system still knew which classification it belonged to and how its cost should be calculated Figure 20.



BIM Classification & Cost Mapping
5D BIM Workflow Prototype - Classification-Driven Cost Mapping

€129.69
Total Project Cost

File Upload

1. Upload IFC Model

IFC Model Loaded Successfully
1 elements with classification codes found

Upload an IFC file with "Classification System New" property set (e.g., EF_25_10_10)

Ready to Convert

2. Upload Cost Data (CSV Format)

Cost Data Loaded Successfully
2 cost entries loaded

Required format: CSV file with columns:
- Classification Code (e.g., EF_25_10_10)
- Unit Cost (e.g., 15)
- Unit of Measurement (e.g., m²)

Convert Excel to CSV:
1. Open Excel file → File → Save As
2. Choose "CSV (Comma delimited)" format
3. Save and upload the .csv file

Ready for cost mapping! Both files loaded successfully.

Classification Mapping

3D Model Viewer (GLTF Mode)
GLTF Model - Optimized for performance

GLTF Mode Working! Total: €129.69

Cost Analysis

€129.69
Total Project Cost
Based on 1 mapped elements

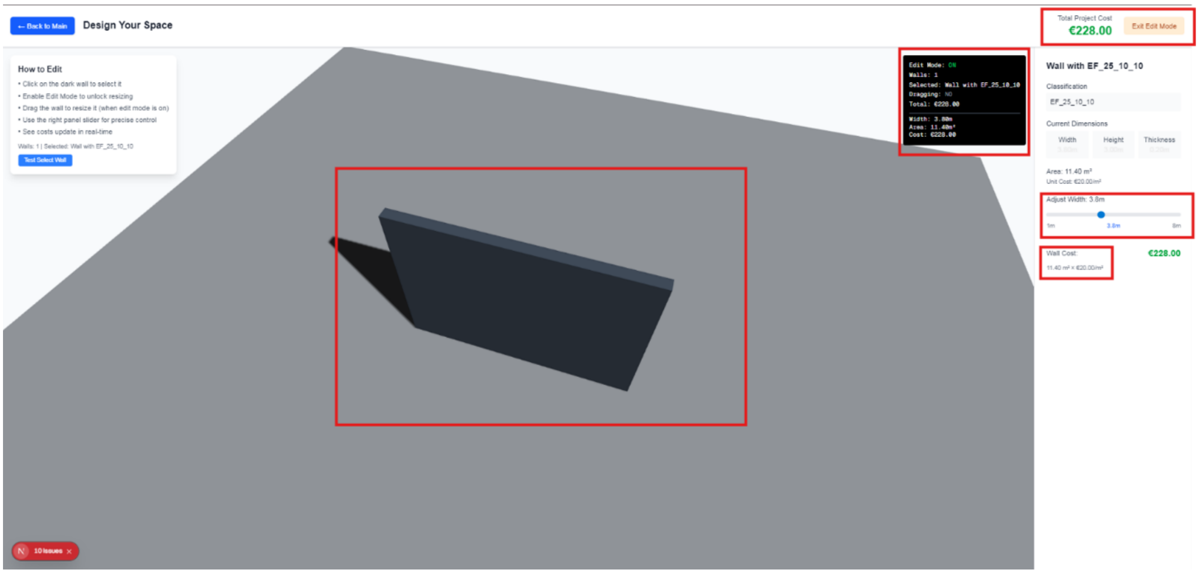
Cost Breakdown by Element Type

Wall (1 elements) €129.69
100.0% of total

Detailed Cost Breakdown

CLASSIFICATION CODE	ELEMENT TYPE	QUANTITY	UNIT COST	TOTAL COST
EF_25_10_10	Wall	12.97 m²	€10.00	€129.69

Figure 20- Successful GLTF conversion



How to Edit

- Click on the dark wall to select it
- Enable Edit Mode to unlock resizing
- Drag the wall to resize it (when edit mode is on)
- Use the right panel slider for precise control
- See costs update in real-time

Walls: 1 | Selected: Wall with EF_25_10_10

Total Project Cost
€228.00

```
Edit Mode: ON
Walls: 1
Selected: Wall with EF_25_10_10
Dragging: NO
Total: €228.00
Width: 3.80m
Area: 11.40m²
Cost: €228.00
```

Wall with EF_25_10_10

Classification
EF_25_10_10

Current Dimensions

Width	Height	Thickness
3.80m	3.00m	0.20m

Area: 11.40 m²
Unit Cost: €20.00/m²

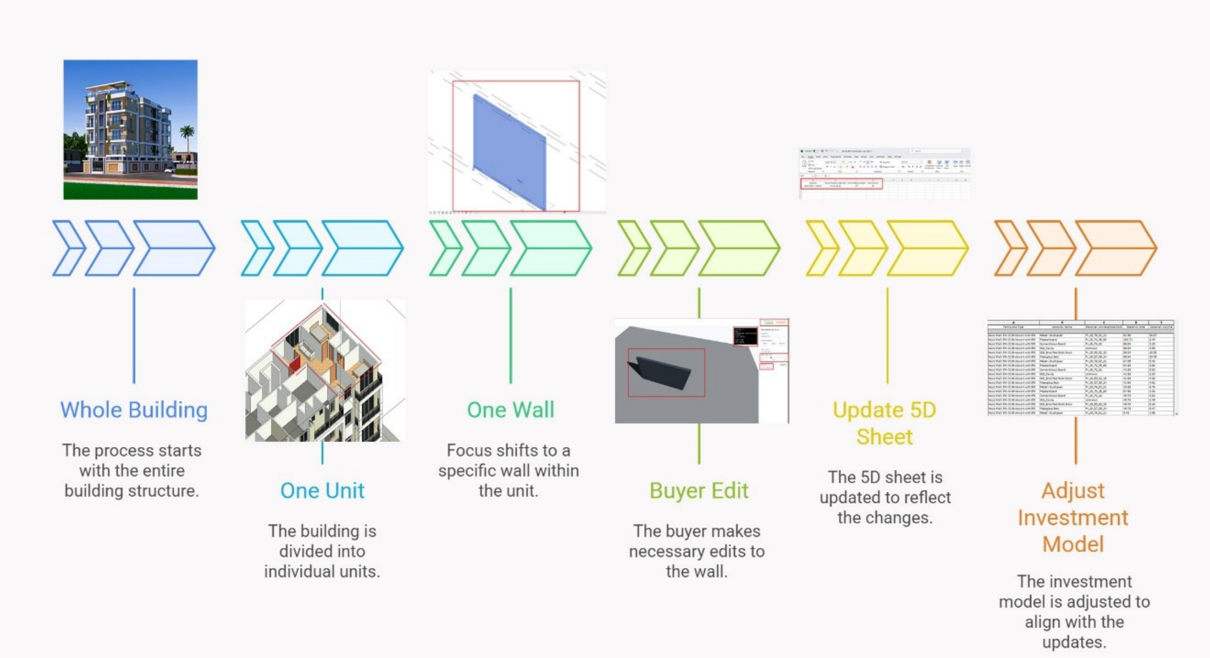
Adjust Width: 3.8m
1m 3.8m 8m

Wall Cost: €228.00
11.40 m² × €20.00/m²

Figure 21- GLTF editing mode

This architecture shows that the prototype is not a stand-alone demo. It is directly connected to the logic of a full 5D estimation workflow:

Whole building → One unit → One wall → Buyer edit → Update in 5D sheet → Adjustment in staged investment model. Workflow is demonstrated in the Figure 22 below.



Whole Building
The process starts with the entire building structure.

One Unit
The building is divided into individual units.

One Wall
Focus shifts to a specific wall within the unit.

Buyer Edit
The buyer makes necessary edits to the wall.

Update 5D Sheet
The 5D sheet is updated to reflect the changes.

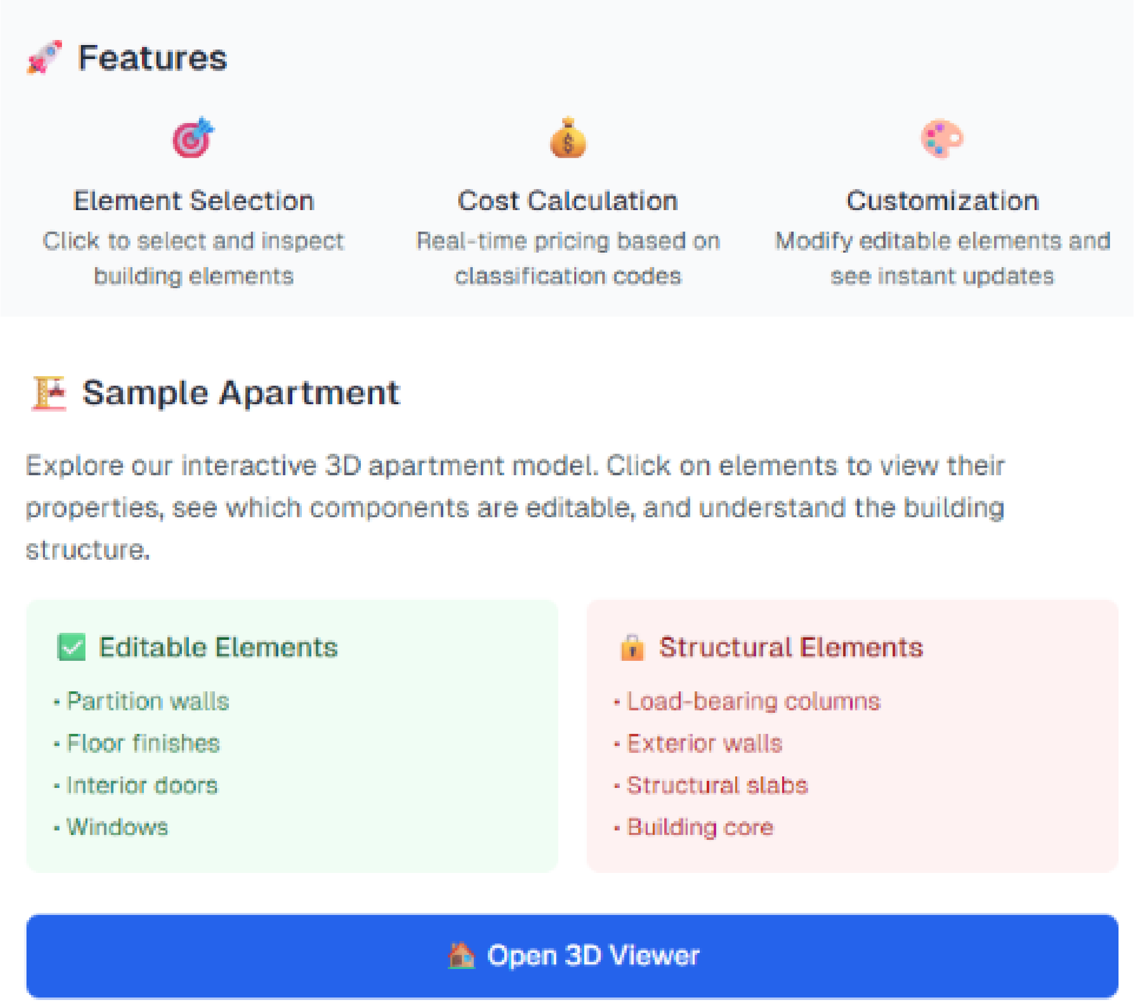
Adjust Investment Model
The investment model is adjusted to align with the updates.

Figure 22- Workflow for this prototype

4.2.2 Interface Features and Buyer Interaction Flow

The web interface of the prototype was developed to make interaction easy for a non-technical buyer. The model could be opened in a browser, and the buyer could move around it using simple controls such as orbit, pan, and zoom. When an element was selected, a side panel appeared showing its details, such as material, area, and cost.

The interface was designed with two clear rules. First, structural elements were locked to prevent any unsafe or invalid changes see Figure 23. These included exterior walls, structural columns, and slabs. They were marked in the model so the buyer could see them but could not modify them see Figure 24 & 25. Second, architectural elements were editable. These included partition walls, wall finishes, doors, windows, and floor coverings. The buyer could select these elements and swap materials or change their dimensions within the allowed range.



🚀 Features

🎯 Element Selection
Click to select and inspect building elements

💰 Cost Calculation
Real-time pricing based on classification codes

🎨 Customization
Modify editable elements and see instant updates

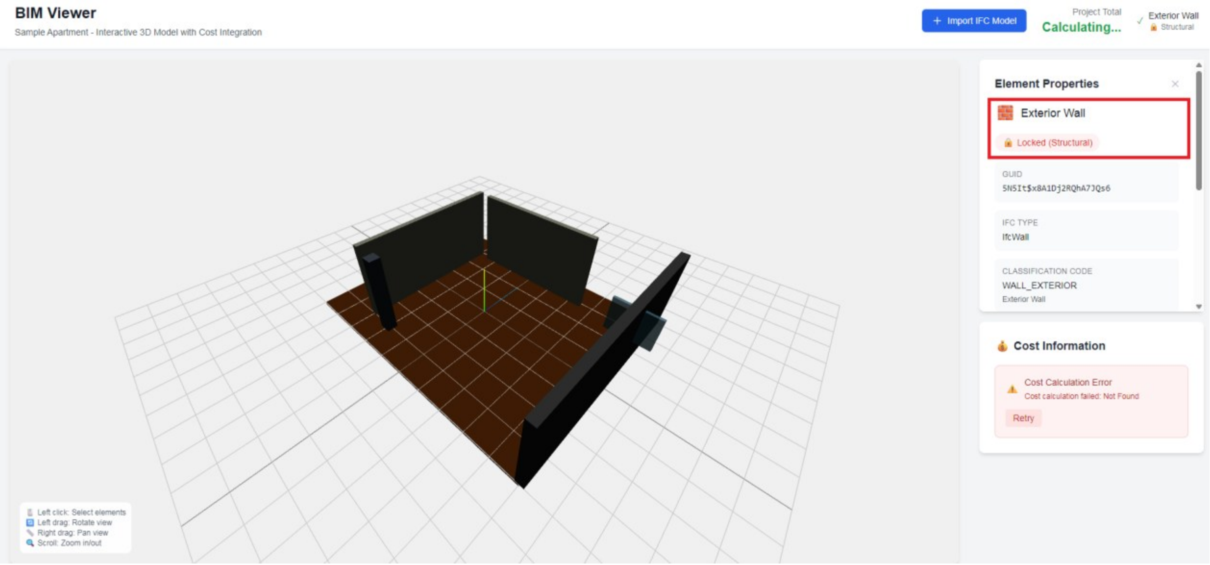
🏗 Sample Apartment

Explore our interactive 3D apartment model. Click on elements to view their properties, see which components are editable, and understand the building structure.

✅ Editable Elements
- Partition walls
- Floor finishes
- Interior doors
- Windows

🔒 Structural Elements
- Load-bearing columns
- Exterior walls
- Structural slabs
- Building core

Figure 23- Editable, non editable element & features



BIM Viewer
Sample Apartment - Interactive 3D Model with Cost Integration

Project Total
Calculating...

✓ Exterior Wall
🔒 Structural

Element Properties

Exterior Wall
🔒 Locked (Structural)

GUID
5N5It$x8A1Dj2RQhA7JQs6

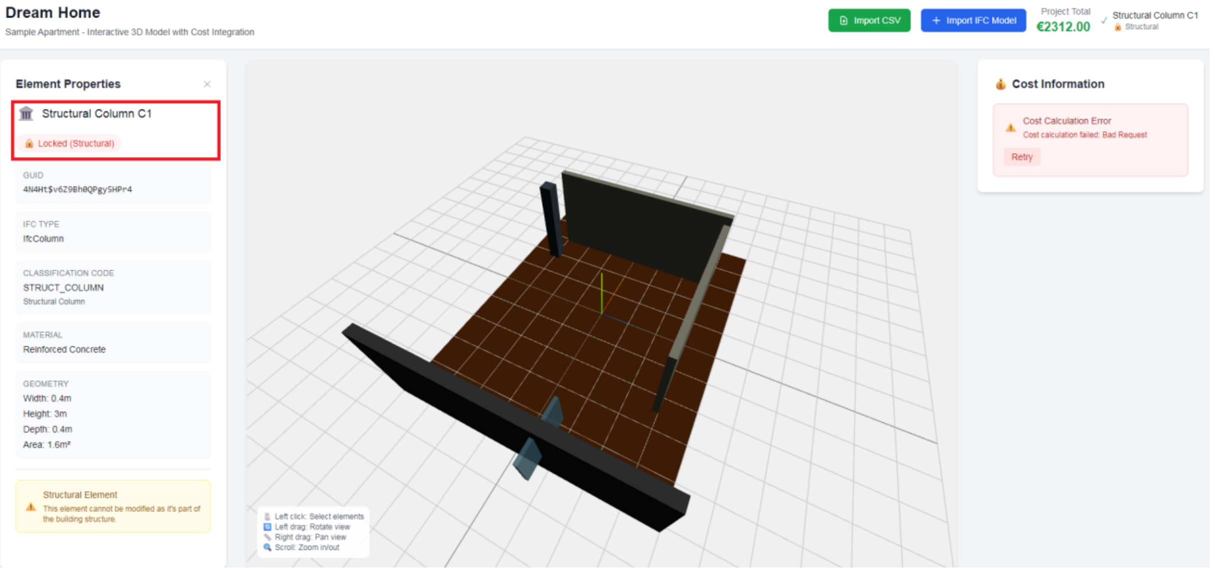
IFC TYPE
IfcWall

CLASSIFICATION CODE
WALL_EXTERIOR
Exterior Wall

Cost Information

⚠ Cost Calculation Error
Cost calculation failed: Not Found

Figure 24- Exterior wall locked



Dream Home
Sample Apartment - Interactive 3D Model with Cost Integration

Project Total
€2312.00

✓ Structural Column C1
🔒 Structural

Element Properties

Structural Column C1
🔒 Locked (Structural)

GUID
4N4Ht$v6Z9Bh0QPgy5HPr4

IFC TYPE
IfcColumn

CLASSIFICATION CODE
STRUCT_COLUMN
Structural Column

MATERIAL
Reinforced Concrete

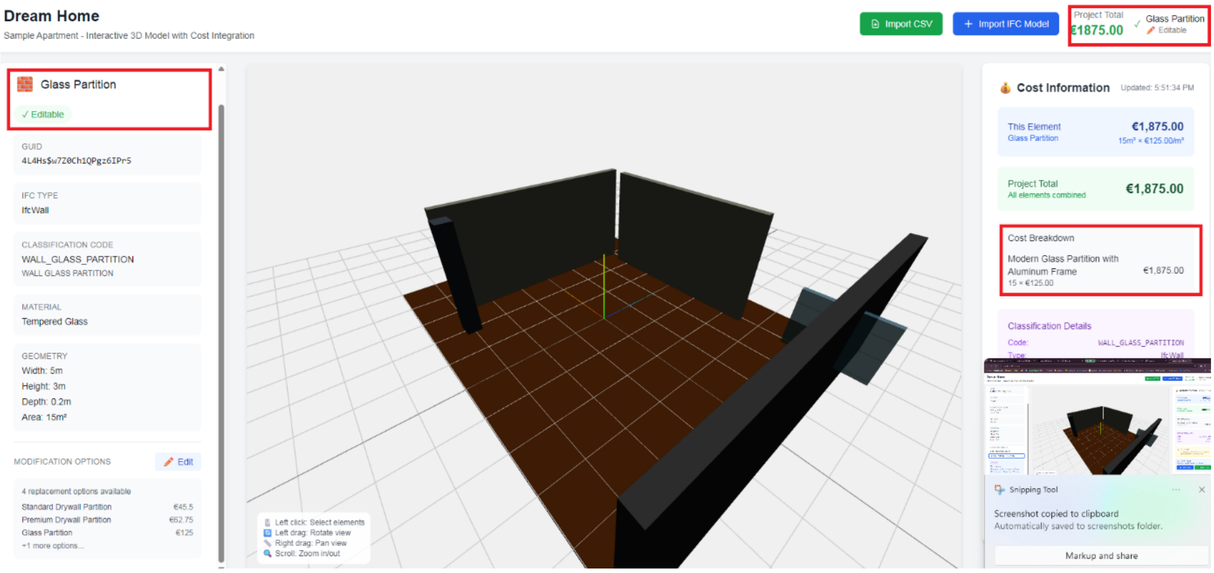
GEOMETRY
Width: 0.4m
Height: 3m
Depth: 0.4m
Area: 1.6m²

⚠ Structural Element
This element cannot be modified as it's part of the building structure.

Cost Information

⚠ Cost Calculation Error
Cost calculation failed: Bad Request

Figure 25- Structure column locked



Dream Home
Sample Apartment - Interactive 3D Model with Cost Integration

Project Total €1875.00 ✓ Glass Partition Editable

Glass Partition
✓ Editable

GUID
4L4Hs$w7Z0Ch1QPgz6IPr5

IFC TYPE
IfcWall

CLASSIFICATION CODE
WALL_GLASS_PARTITION
WALL GLASS PARTITION

MATERIAL
Tempered Glass

GEOMETRY
Width: 5m
Height: 3m
Depth: 0.2m
Area: 15m²

MODIFICATION OPTIONS

4 replacement options available

Standard Drywall Partition	€45.5
Premium Drywall Partition	€62.75
Glass Partition	€125
+1 more options...	

Cost Information Updated: 5:51:34 PM

This Element
Glass Partition
€1,875.00
15m² × €125.00/m²

Project Total
All elements combined
€1,875.00

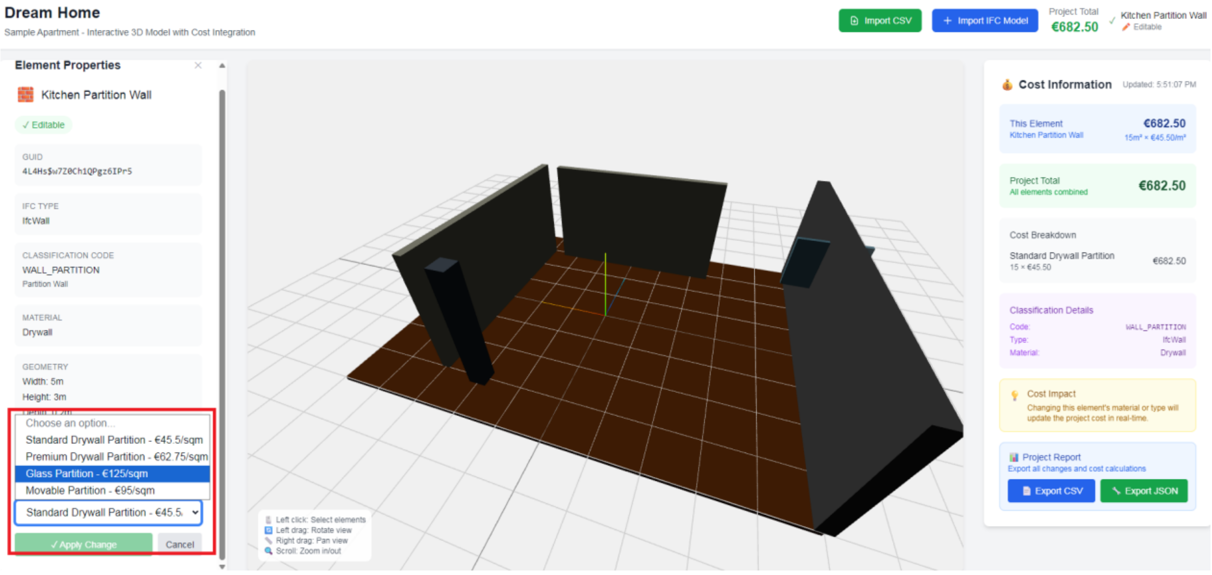
Cost Breakdown
Modern Glass Partition with Aluminum Frame €1,875.00
15 × €125.00

Classification Details
Code: WALL_GLASS_PARTITION
Type: IfcWall

Snipping Tool
Screenshot copied to clipboard
Automatically saved to screenshots folder.

Figure 26- Editable element

For example, if the buyer clicked on a partition wall, the interface displayed the available options for finishes. Materials could be swapped, such as plaster to ceramic tiles. Each option carried its classification number, which was linked to the cost database. As soon as the buyer selected a new option, the cost was updated instantly in the side panel.



Dream Home
Sample Apartment - Interactive 3D Model with Cost Integration

Project Total €682.50 ✓ Kitchen Partition Wall Editable

Element Properties

Kitchen Partition Wall
✓ Editable

GUID
4L4Hs$w7Z0Ch1QPgz6IPr5

IFC TYPE
IfcWall

CLASSIFICATION CODE
WALL_PARTITION
Partition Wall

MATERIAL
Drywall

GEOMETRY
Width: 5m
Height: 3m

Choose an option...
Standard Drywall Partition - €45.5/sqm
Premium Drywall Partition - €62.75/sqm
Glass Partition - €125/sqm
Movable Partition - €95/sqm

Standard Drywall Partition - €45.5

Cost Information Updated: 5:51:07 PM

This Element
Kitchen Partition Wall
€682.50
15m² × €45.50/m²

Project Total
All elements combined
€682.50

Cost Breakdown
Standard Drywall Partition €682.50
15 × €45.50

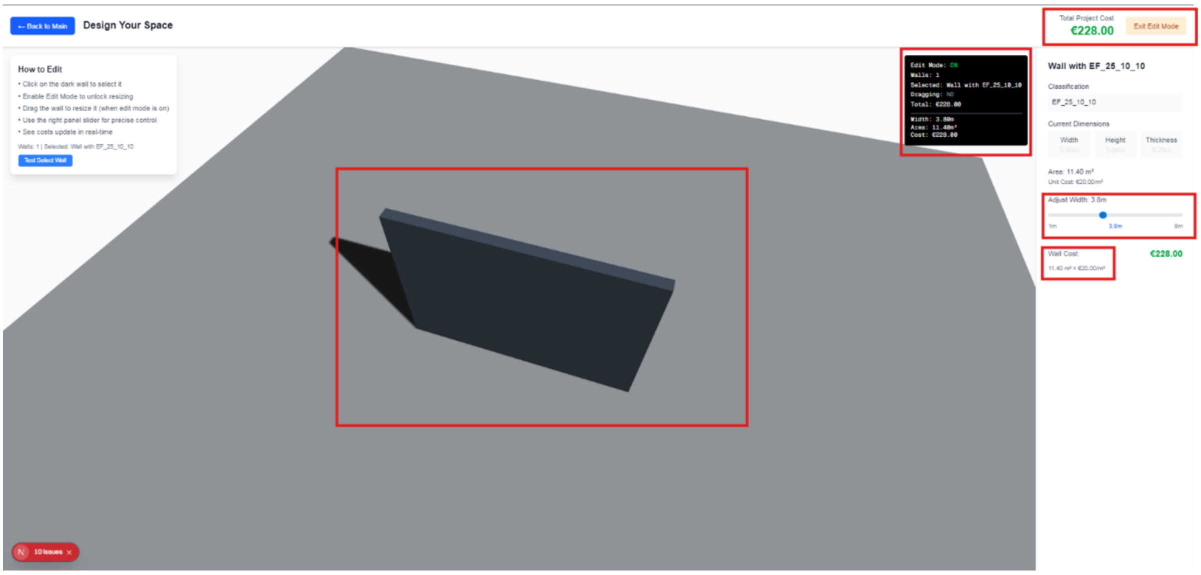
Classification Details
Code: WALL_PARTITION
Type: IfcWall
Material: Drywall

Cost Impact
Changing this element's material or type will update the project cost in real-time.

Project Report
Export all changes and cost calculations

Figure 27- Material swapping

The same process applied to wall resizing. By adjusting the wall length or height, the area was recalculated, and the new cost was shown which can be seen in Figure 28. This made the effect of design changes clear and immediate. Even a small change in wall size or finish could be seen in terms of its financial impact.



How to Edit
- Click on the dark wall to select it
- Enable Edit Mode to unlock resizing
- Drag the wall to resize it (when edit mode is on)
- Use the right panel slider for precise control
- See costs update in real-time

Walls: 1 | Selected: Wall with EF_25_10_10

Total Project Cost
€228.00

```
Edit Mode: ON
Walls: 1
Selected: Wall with EF_25_10_10
Dragging: NO
Total: €228.00

Width: 3.80m
Area: 11.40m²
Cost: €228.00
```

Wall with EF_25_10_10

Classification: EF_25_10_10

Current Dimensions

Width	Height	Thickness
3.80m	3.00m	0.20m

Area: 11.40 m²
Unit Cost: €20.00/m²

Adjust Width: 3.8m
1m 3.8m 8m

Wall Cost: €228.00
11.40 m² × €20.00/m²

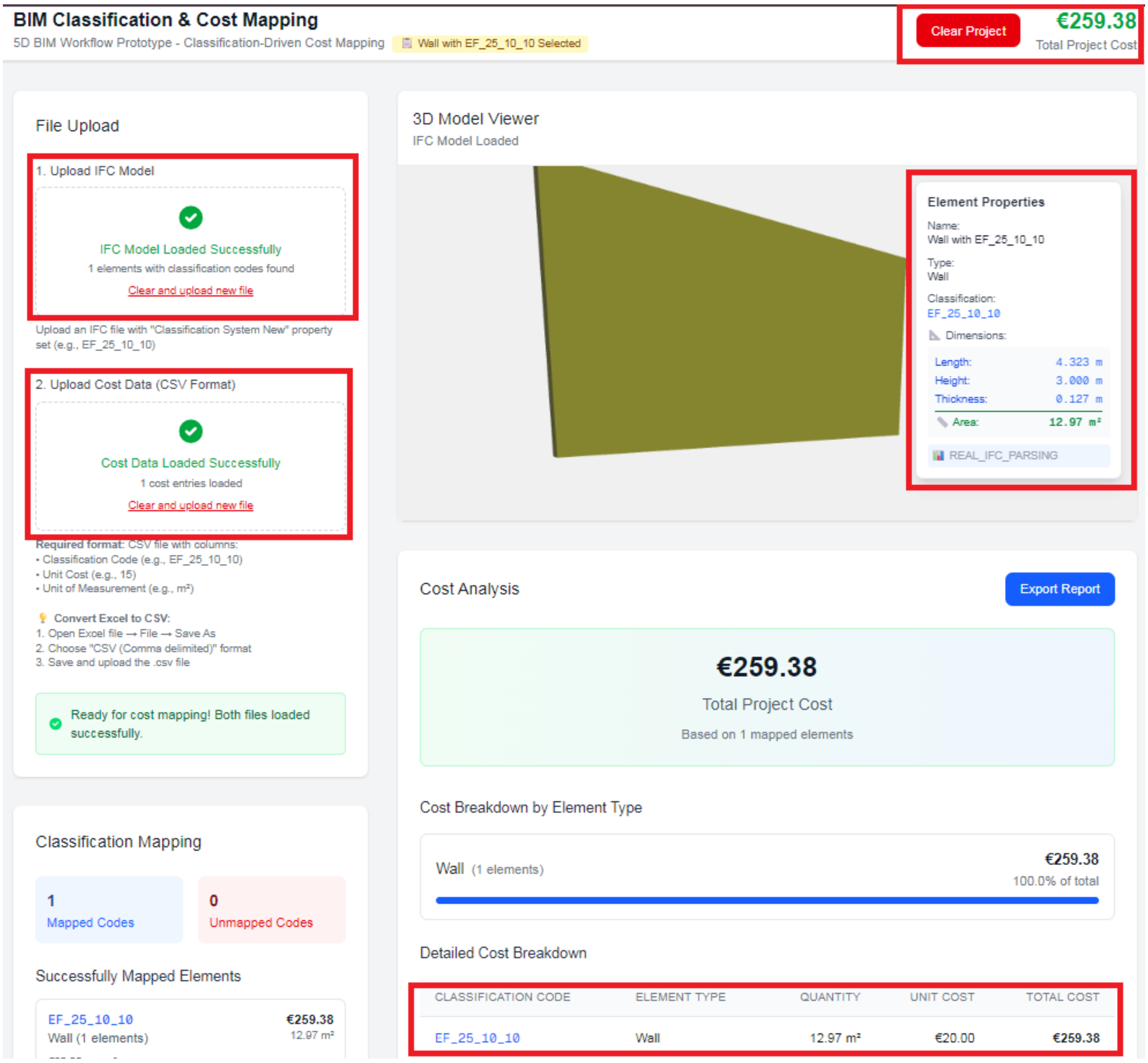
Figure 28- Resizing wall geometry and live cost updates

The interface also displayed both the individual element cost and the total cost of all buyer selections. This gave the buyer an overview of how their choices affected the total investment in the unit. When they were satisfied, they could confirm the changes. At this point, the updated cost data was recorded in Excel, ready to be uploaded into the Common Data Environment (CDE) and reflected in the staged investment model.

4.2.3 Backend Cost Mapping and Classification Logic

The most important part of the prototype was the way costs were calculated in the background. This was done by linking the classification numbers from the IFC model to the unit costs stored in an Excel sheet. Each element in the apartment had a classification code, such as a wall finish or a partition type. These codes acted like unique IDs, making sure that the correct unit cost was always applied to the correct element.

The Excel sheet used in the prototype was created from the 5D estimation of the whole building. It contained classification numbers, unit rates, and measurements for all building elements. For the test, the sheet was simplified, but the logic stayed the same. When the buyer interacted with the wall in the prototype, the system read the classification number from the model, matched it with the one in the Excel sheet, and fetched the correct unit rate.



BIM Classification & Cost Mapping
5D BIM Workflow Prototype - Classification-Driven Cost Mapping
Wall with EF_25_10_10 Selected

€259.38
Total Project Cost

File Upload

1. Upload IFC Model
IFC Model Loaded Successfully
1 elements with classification codes found

Upload an IFC file with "Classification System New" property set (e.g., EF_25_10_10)

2. Upload Cost Data (CSV Format)
Cost Data Loaded Successfully
1 cost entries loaded

Required format: CSV file with columns:
- Classification Code (e.g., EF_25_10_10)
- Unit Cost (e.g., 15)
- Unit of Measurement (e.g., m²)

Convert Excel to CSV:
1. Open Excel file → File → Save As
2. Choose "CSV (Comma delimited)" format
3. Save and upload the .csv file

Ready for cost mapping! Both files loaded successfully.

Classification Mapping

1 Mapped Codes
0 Unmapped Codes

Successfully Mapped Elements

EF_25_10_10 €259.38
Wall (1 elements) 12.97 m²

3D Model Viewer
IFC Model Loaded

Element Properties
Name:
Wall with EF_25_10_10
Type:
Wall
Classification:
EF_25_10_10
Dimensions:
Length: 4.323 m
Height: 3.000 m
Thickness: 0.127 m
Area: 12.97 m²
REAL_IFC_PARSING

Cost Analysis

€259.38
Total Project Cost
Based on 1 mapped elements

Cost Breakdown by Element Type

Wall (1 elements) €259.38
100.0% of total

Detailed Cost Breakdown

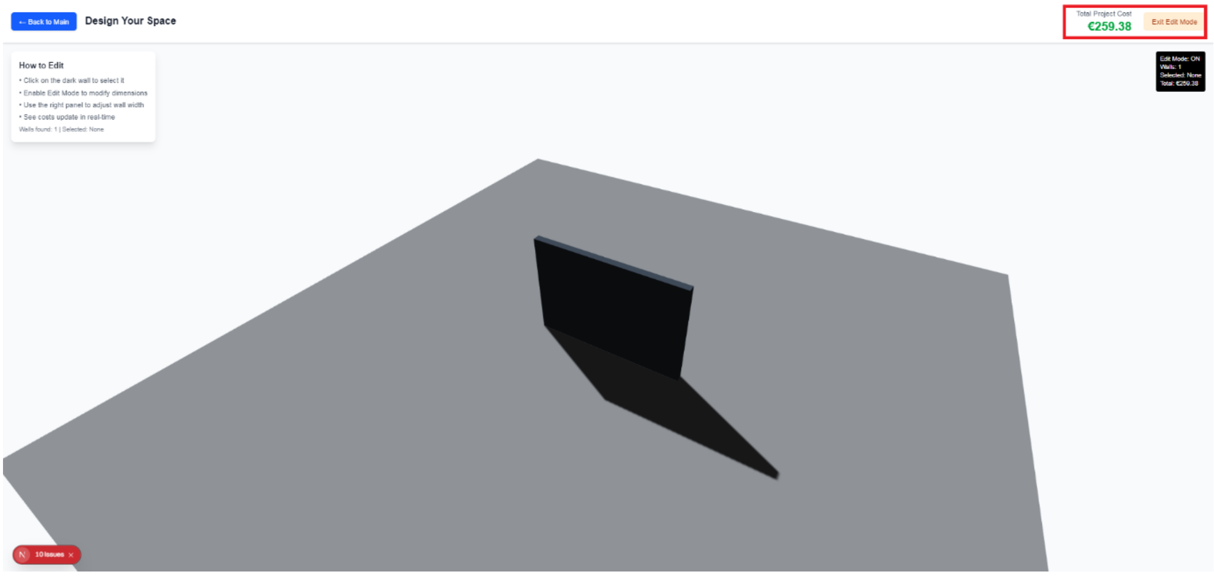
CLASSIFICATION CODE	ELEMENT TYPE	QUANTITY	UNIT COST	TOTAL COST
EF_25_10_10	Wall	12.97 m²	€20.00	€259.38

Figure 29- Cost mapping and classification logic

Quantities were calculated automatically from the geometry. For wall, the system used surface area. For example, when the buyer increased the length of a wall, the surface area changed and the total cost was recalculated instantly. The result was then displayed in the interface, please see Figure 30 & 31.

The backend also kept a record of every change. Each selection was logged with its classification number, the new material, the measured quantity, and the updated price. This log was important because it acted as an audit trail. It showed exactly what the buyer changed, how much it cost, and when the change was made.

By structuring the cost logic in this way, the prototype was able to provide real time feedback to the buyer while remaining connected to the professional cost sheet used by the project team.



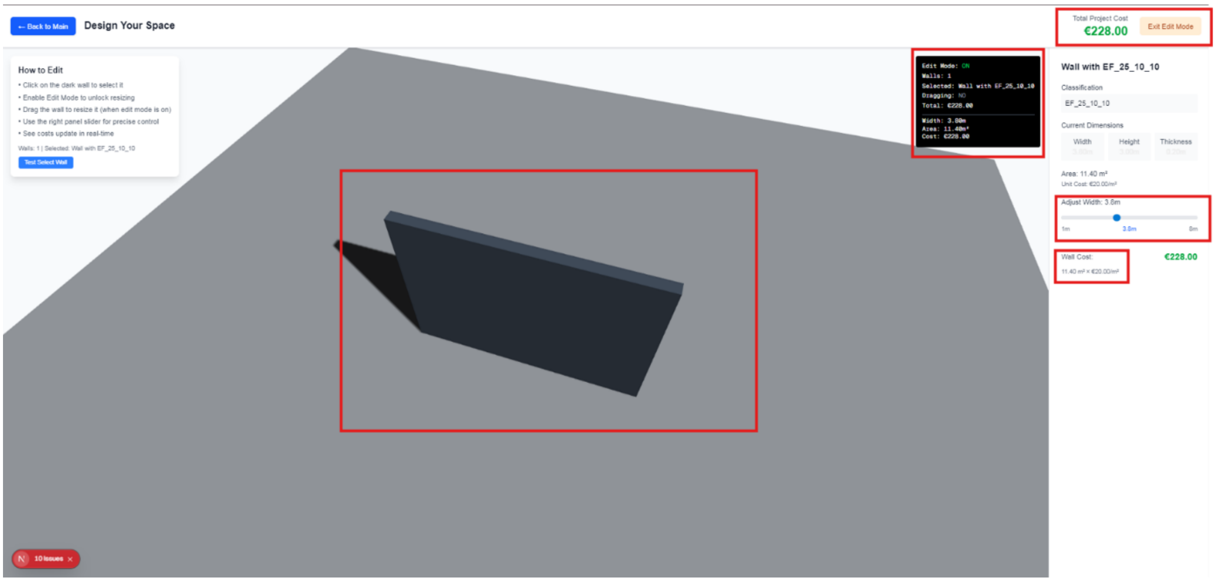
€259.38

How to Edit
- Click on the dark wall to select it
- Enable Edit Mode to modify dimensions
- Use the right panel to adjust wall width
- See costs update in real-time

Walls found: 1 | Selected: None

Edit Mode: ON
Walls: 1
Selected: None
Total: €259.38

Figure 30- Initial wall dimension and cost



€228.00

How to Edit
- Click on the dark wall to select it
- Enable Edit Mode to unlock resizing
- Drag the wall to resize it (when edit mode is on)
- Use the right panel slider for precise control
- See costs update in real-time

Walls: 1 | Selected: Wall with EF_25_10_10

```
Edit Mode: ON
Walls: 1
Selected: Wall with EF_25_10_10
Dragging: NO
Total: €228.00

Width: 3.80m
Area: 11.40m²
Cost: €228.00
```

Wall with EF_25_10_10

Classification: EF_25_10_10

Area: 11.40 m²
Unit Cost: €20.00/m²

Adjust Width: 3.8m

Wall Cost: €228.00
11.40 m² × €20.00/m²

Figure 31- After editing wall dimension and live cost updates

4.2.4 Technical Challenges

Building the prototype was not a smooth process. It required many rounds of testing and fixing errors before reaching a working version. Nearly one hundred attempts were made to achieve the results shown in this chapter.

One of the first problems came during the parsing of the IFC file. At times the parser failed to load the geometry correctly, which meant that elements were not displayed in the viewer. This made it difficult to test interactions, because even though the classification numbers were being read, the buyer could not see the model on the screen.

How to Edit

- Click on the dark wall to select it
- Enable Edit Mode to unlock resizing
- Drag the wall to resize it (when edit mode is on)
- Use the right panel slider for precise control
- See costs update in real-time

Walls: 1 | Selected: Wall with EF_25_10_10

```
Edit Mode: ON
Walls: 1
Selected: Wall with EF_25_10_10
Dragging: NO
Total: €264.00

Width: 4.40m
Area: 13.20m²
Cost: €264.00
```

Wall with EF_25_10_10

Classification: EF_25_10_10

Current Dimensions: Width, Height, Thickness

Area: 13.20 m²
Unit Cost: €20.00/m²

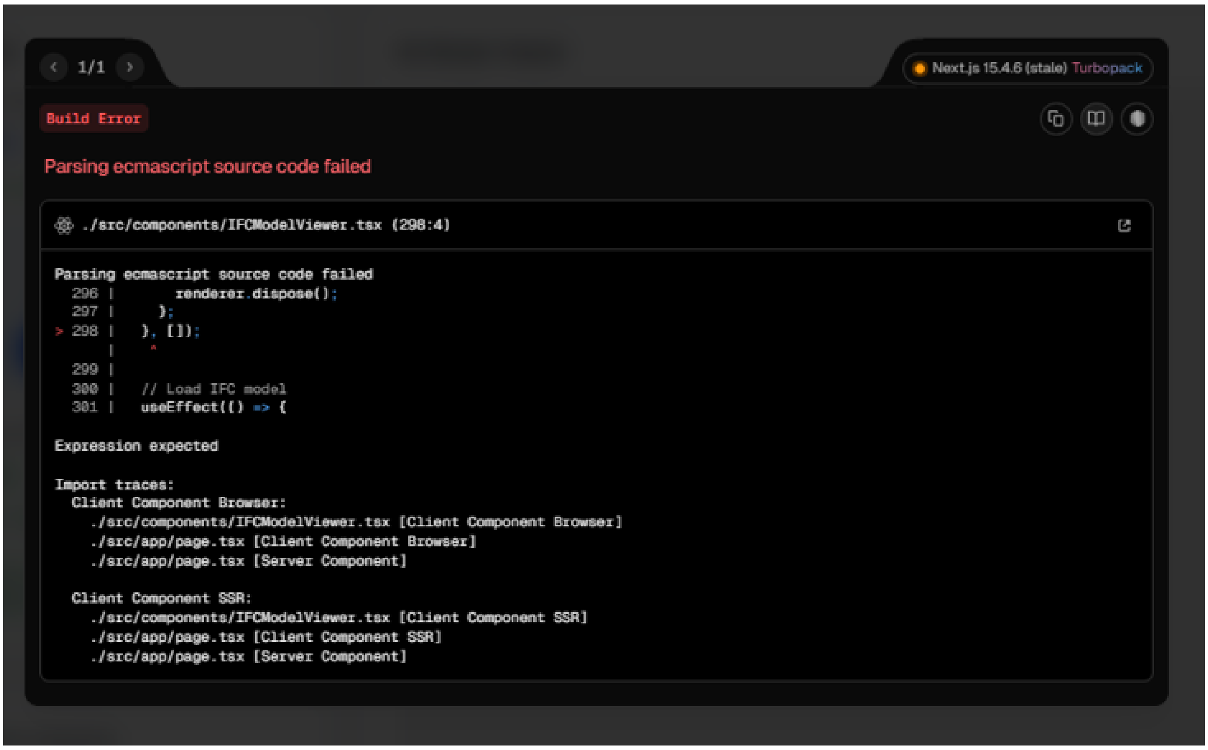
Adjust Width: 4.4m (1m – 4.4m – 8m)

Wall Cost: €264.00
13.20 m² × €20.00/m²

Figure 32- Geometry lost during conversion process

Another major issue appeared with Three.js rendering. On some occasions, the geometry did not respond to edits or disappeared completely when changes were applied. In other cases, the cost updated correctly, but the visual model did not change. This showed how fragile the connection could be between the geometry and the cost logic, and it required repeated adjustments before both parts worked together.

There were also difficulties with maintaining consistency in classification numbers. Sometimes, the link between the IFC model and the Excel sheet did not match correctly, which led to errors in cost calculation. For example, a wall might show the wrong unit rate or fail to trigger an update at all. These problems had to be corrected by carefully checking the classification mapping in the backend.



```
Build Error

Parsing ecmascript source code failed

./src/components/IFCModelViewer.tsx (298:4)

Parsing ecmascript source code failed
  296 |       renderer.dispose();
  297 |     };
> 298 |   }, []);
      |    ^
  299 |
  300 |   // Load IFC model
  301 |   useEffect(() => {

Expression expected

Import traces:
  Client Component Browser:
    ./src/components/IFCModelViewer.tsx [Client Component Browser]
    ./src/app/page.tsx [Client Component Browser]
    ./src/app/page.tsx [Server Component]

  Client Component SSR:
    ./src/components/IFCModelViewer.tsx [Client Component SSR]
    ./src/app/page.tsx [Client Component SSR]
    ./src/app/page.tsx [Server Component]
```

Figure 33- Parsing errors

Despite these challenges, the prototype was able to demonstrate its main purpose: showing buyers the immediate effect of their design choices on cost. The technical errors were part of the learning process and helped to prove where the workflow is strong and where future improvement is required.

4.3 Case Study Setup

To test the prototype in a realistic context, a residential building was chosen as the case study. The building is a G+4 apartment block located in Patna, India. Each floor of the building contains three flats, with different layouts and floor areas. This setting was selected because it reflects the type of multi-unit residential projects where buyers often request design changes and where staged investment models are commonly used.

Figure 34- Case study building

From this building, one flat unit was taken as the focus of the study. Within that unit, all elements were modelled with classification numbers so that they could be distinguished from the elements of other flats in the same building.

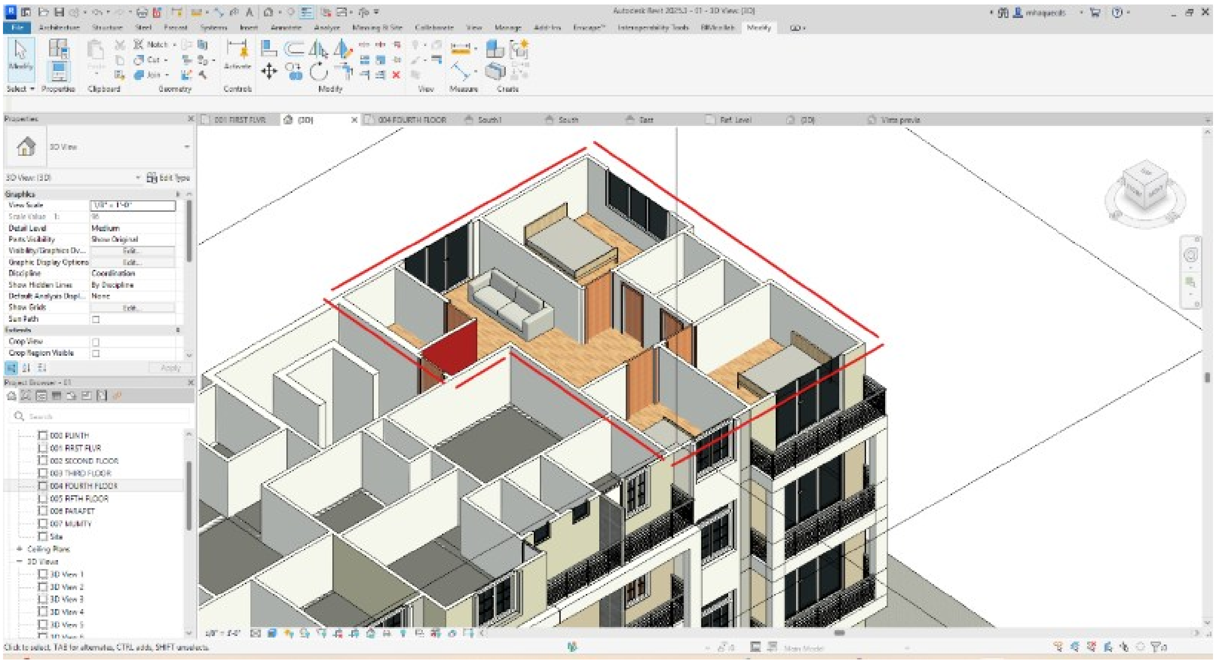
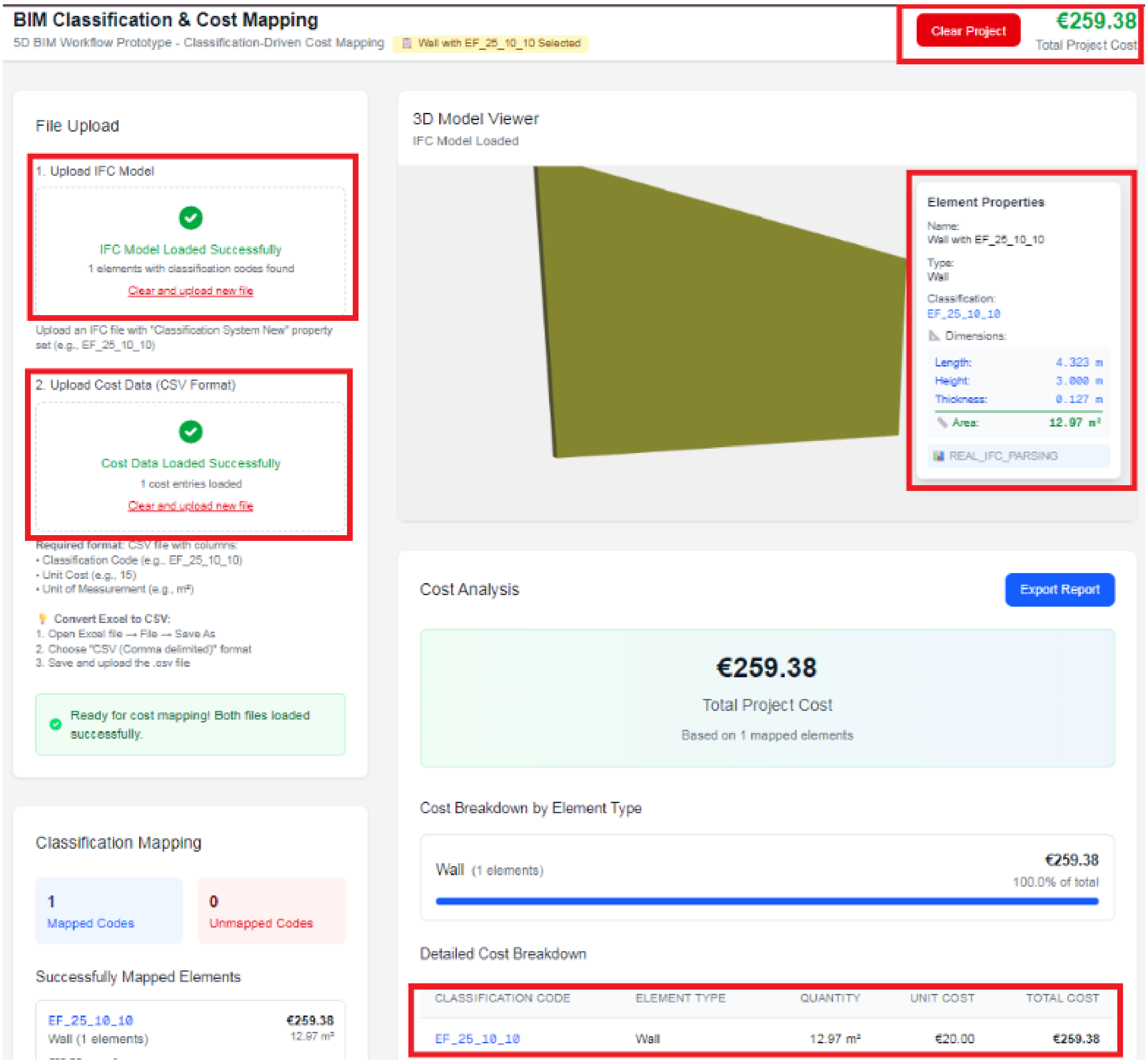


Figure 35- Flat Unit wall

For the prototype test, a single wall in the kitchen of the selected flat was used which is highlighted with red colour in the flat unit and can be seen in Figure 35. This wall was chosen for two reasons. First, it represented a typical interior partition that buyers often want to customise, for example by changing its finish or adjusting its size. Second, limiting the test to one wall made the process more practical, since the focus of the study was to prove the concept of dynamic cost updates rather than to test every element of the flat.

This choice also reflects how real buyers interact with design tools. Buyers are usually non-technical and giving them full freedom in an empty modelling space would be overwhelming. Instead, they are more comfortable making small and guided changes to an existing layout rather than starting from scratch. Research confirms that buyers prefer structured opportunities for customisation, supported by clear visualisations, rather than open-ended design freedom, which can create confusion and slow decision-making (Puķīte and Geipele, 2015; Zainon et al., 2020). For this reason, the case study began with a ready-made 3D model of the flat rather than a blank space, ensuring that the buyer could focus on meaningful modifications without being lost in unnecessary complexity.

The selected kitchen wall carried a unique classification number and was connected to the 5D cost sheet of the entire building. This meant that even though only one wall was being tested in the prototype, the changes were still reflected in the same cost structure that underpins the staged investment model for the whole project. By changing the wall's material or size in the web interface, the system updated the cost instantly and displayed it to the buyer. These updates were then recorded in Excel, which could be reintegrated into the Common Data Environment (CDE) and linked back to the staged payment schedule.



Upload an IFC file with "Classification System New" property set (e.g., EF_25_10_10)

Required format: CSV file with columns:
- Classification Code (e.g., EF_25_10_10)
- Unit Cost (e.g., 15)
- Unit of Measurement (e.g., m²)

Convert Excel to CSV:
1. Open Excel file → File → Save As
2. Choose "CSV (Comma delimited)" format
3. Save and upload the .csv file

Ready for cost mapping! Both files loaded successfully.

EF_25_10_10 €259.38
Wall (1 elements) 12.97 m²

Name: Wall with EF_25_10_10
Type: Wall
Classification: EF_25_10_10
Dimensions:

Length:	4.323 m
Height:	3.000 m
Thickness:	0.127 m
Area:	12.97 m²

€259.38
Total Project Cost
Based on 1 mapped elements

Cost Breakdown by Element Type

Wall (1 elements) €259.38
100.0% of total

Detailed Cost Breakdown

CLASSIFICATION CODE	ELEMENT TYPE	QUANTITY	UNIT COST	TOTAL COST
EF_25_10_10	Wall	12.97 m²	€20.00	€259.38

Figure 36- IFC and 5D excel sheet parsing

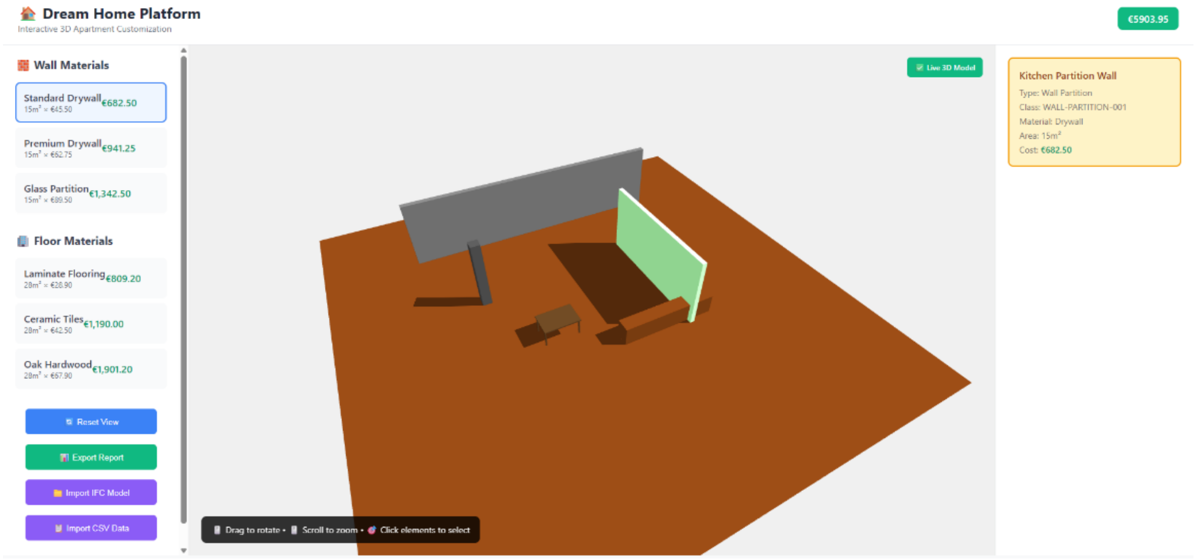
4.4 Results from Prototype Testing

The prototype was tested using the kitchen wall of the selected flat unit. The aim was to demonstrate how changes made by a buyer in the web interface are reflected in real-time cost updates. The results confirmed that the workflow could link the classification numbers in the IFC model with the unit prices in the Excel sheet and display the cost impact directly to the buyer.

4.4.1 Accuracy of Cost Feedback

One of the most important findings from the prototype test was that cost updates appeared instantly when a buyer changed either the material or the size of an element. The system was able to measure the element's geometry, match it to the right classification number, and apply the correct unit price from the cost sheet without delay. These elements were assumed based on our case study to taste since it was becoming so difficult to import the whole unit in this prototype.

The first test was carried out on the kitchen partition wall. The wall had an area of 15 m² and was initially set as Standard Drywall at a rate of €45.50/m², giving a total cost of €682.50. When the buyer swapped this to Premium Drywall, the unit rate updated to €62.75/m², and the total cost rose to €941.25. Replacing it again with a Glass Partition at €89.50/m² pushed the total cost further to €1,342.50 Figure 37 & 38. This showed that the system could correctly apply different finishes to the same wall and reflect their costs instantly.

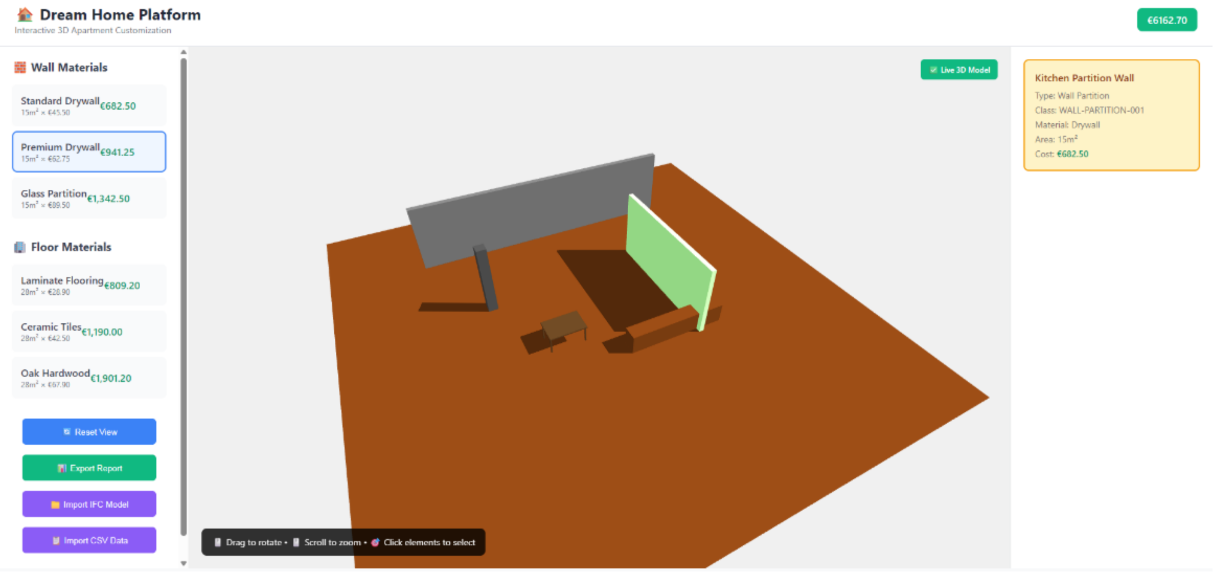


Standard Drywall €682.50
15m² × €45.50
Premium Drywall €941.25
15m² × €62.75
Glass Partition €1,342.50
15m² × €89.50

Laminate Flooring €809.20
28m² × €28.90
Ceramic Tiles €1,190.00
28m² × €42.50
Oak Hardwood €1,901.20
28m² × €67.90

Kitchen Partition Wall
Type: Wall Partition
Class: WALL-PARTITION-001
Material: Drywall
Area: 15m²
Cost: €682.50

Figure 37- wall material Standard and cost



Wall Materials

Standard Drywall €682.50
15m² × €45.50

Premium Drywall €941.25
15m² × €62.75

Glass Partition €1,342.50
15m² × €89.50

Floor Materials

Laminate Flooring €809.20
28m² × €28.90

Ceramic Tiles €1,190.00
28m² × €42.50

Oak Hardwood €1,901.20
28m² × €67.90

Kitchen Partition Wall
Type: Wall Partition
Class: WALL-PARTITION-001
Material: Drywall
Area: 15m²
Cost: €682.50

Figure 38- wall material changes & live cost changes updates

The second test focused on the floor finish of the same flat. The floor had an area of 28 m². When the material was set to Laminate Flooring at €28.90/m², the cost was €809.20. Changing the finish to Ceramic Tiles updated the rate to €42.50/m², increasing the cost to €1,190.00. Finally, switching to Oak Hardwood at €67.90/m² raised the cost to €1,901.20 Figure 39 & 40. These changes were calculated and displayed instantly on the buyer interface.

Wall Materials

Standard Drywall €682.50
15m² × €45.50

Premium Drywall €941.25
15m² × €62.75

Glass Partition €1,342.50
15m² × €89.50

Floor Materials

Laminate Flooring €809.20
28m² × €28.90

Ceramic Tiles €1,190.00
28m² × €42.50

Oak Hardwood €1,901.20
28m² × €67.90

Main Floor
Type: Floor Finish
Class: FLOOR-FINISH-001
Material: Laminate Flooring
Area: 28m²
Cost: €809.20

Figure 39- Floor material changes & live cost changes live

Dream Home Platform
Interactive 3D Apartment Customization

€6162.70

Wall Materials

Standard Drywall 15m² × €45.50	€682.50
Premium Drywall 15m² × €62.75	€941.25
Glass Partition 15m² × €89.50	€1,342.50

Floor Materials

Laminate Flooring 28m² × €28.90	€809.20
Ceramic Tiles 28m² × €42.50	€1,190.00
Oak Hardwood 28m² × €67.90	€1,901.20

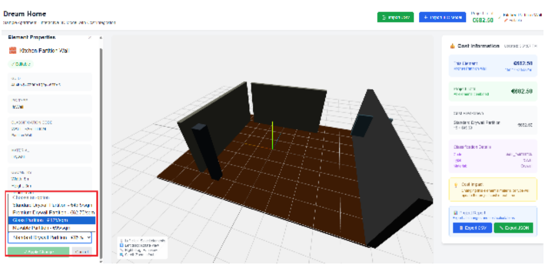
Main Floor
Type: Floor Finish
Class: FLOOR-FINISH-001
Material: Laminate Flooring
Area: 28m²
Cost: €809.20

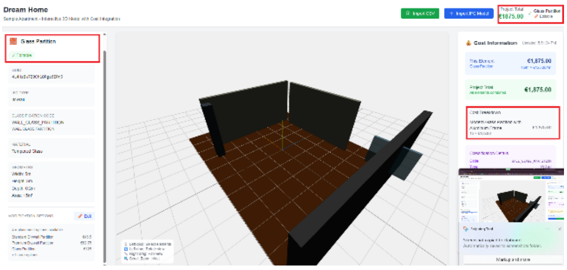
Figure 40- Floor material changes & live cost changes live

Together, these examples demonstrated that the prototype could combine accurate geometry with classification-linked cost data. Whether the change was on walls or floors, the system consistently gave the buyer clear and transparent feedback about the financial effect of their choices in real time.

4.4.2 Responsiveness of Buyer Interface

The buyer interface responded smoothly to edits. Partition walls and finishes could be changed without delay, and the updated cost appeared in the side panel immediately. Locked elements, such as exterior walls and columns, remained visible but uneditable, confirming that the system could control what changes were allowed.





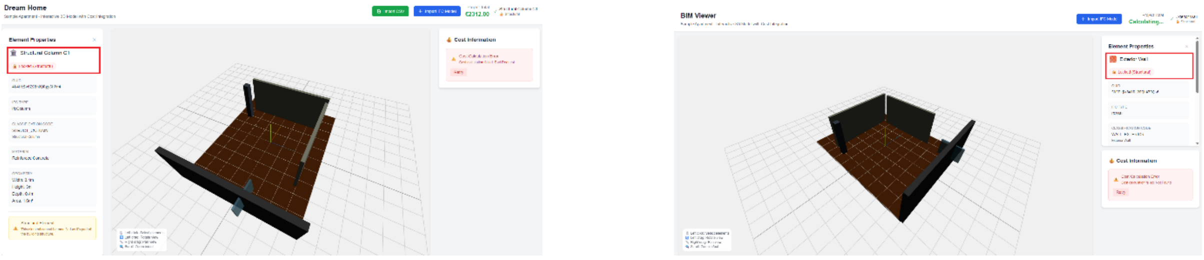


Figure 41- Buyer’s interaction and limitations

4.4.3 Reintegration into CDE / Delta Export

Once the buyer completed their changes, the updated cost data was stored in Excel. This file could then be uploaded into a Common Data Environment (CDE) such as Autodesk Construction Cloud or Dalux. In the staged investment model, the instalments amounts were adjusted automatically to reflect the new cost. This proved that buyer edits at unit level could be connected back to the global project data.

4.4.4 Usability Observations

The tests also highlighted some challenges. At times, the geometry did not update visually, even though the cost changed. In other cases, the classification numbers failed to match correctly, leading to errors in cost calculation. These issues were solved through repeated iteration but showed the limits of the current workflow. Despite these errors, the prototype achieved its main goal of proving that real-time cost updates can be shown to buyers in a simplified interface.

How to Edit
- Click on the dark wall to select it
- Enable Edit Mode to unlock resizing
- Drag the wall to resize it (when edit mode is on)
- Use the right panel slider for precise control
- See costs update in real-time

Walls: 1 | Selected: Wall with EF_25_10_10

```
Edit Mode: ON
Walls: 1
Selected: Wall with EF_25_10_10
Dragging: NO
Total: €264.00

Width: 4.40m
Area: 13.20m²
Cost: €264.00
```

Area: 13.20 m²
Unit Cost: €20.00/m²
Adjust Width: 4.4m
13.20 m² × €20.00/m²

Figure 42- Geometry missing

4.5 Summary

This chapter presented the development and testing of the prototype. The system was based on a standard 5D BIM process, where every element of the building carried a classification number linked with a unit cost. The 5D Excel sheet for the whole building acted as the cost backbone, and from this, one flat unit and one wall were used for testing in the prototype.

The development process showed how IFC models could be converted to GLTF for easier editing in a web browser while keeping classification numbers and quantities. A simple buyer interface was created, where architectural elements could be changed but structural elements were locked. When a buyer resized a wall or swapped its material, the system recalculated the cost in real time and displayed it clearly on the screen.

The case study confirmed that even a small change in one wall could be tracked correctly through the classification system and reflected in the 5D Excel sheet. This updated file could then be uploaded into a Common Data Environment (CDE), where it would adjust the staged investment model automatically.

At the same time, the testing also revealed challenges. Errors in parsing, mismatches in classification numbers, and rendering problems with Three.js showed that the workflow was not always stable. However, the main purpose was achieved: the prototype proved that buyers can be given a simple interface to make design changes and immediately see how those choices affect their costs and staged payments.

5 DISCUSSION

5.1 Interpretation of Results against Objectives

The research set out five objectives, each tested against the prototype developed in this study. The first objective, which focused on creating a platform for controlled customisation, was largely achieved. The prototype established clear boundaries by locking structural elements and allowing only predefined architectural components to be modified. This was evident in the case study where the kitchen partition wall could be customised by changing its finish between plaster, premium drywall, and glass. The presence of locked slabs and exterior walls confirmed that buyers were offered freedom of choice without compromising structural safety.

The second objective, linking design changes to transparent cost data, was met with high reliability. Every modification made in the buyer interface triggered an immediate recalculation in the backend cost sheet. A clear example was the change of floor finish from laminate (€28.90/m²) to oak hardwood (€67.90/m²), which updated the total cost from €809.20 to €1,901.20 (Figure 4.28). These adjustments were recorded accurately through classification codes embedded in the IFC model, ensuring that the outputs were not only visual but also financially traceable.

The third objective, ensuring interoperability with professional BIM workflows, was only partially achieved. While the interface worked in GLTF format for lightweight visualisation, professional compatibility was maintained through structured Excel exports. These exports contained classification-linked updates that could be reintegrated into a Common Data Environment (CDE) to adjust staged investment schedules. However, the process did not extend to full IFC regeneration, which remains dependent on professional intervention.

The fourth objective was to demonstrate the workflow in a realistic case study. This was accomplished by applying the prototype to one flat in the G+4 residential building and limiting testing to a single wall. This narrow scope was deliberate, reflecting the practical need to provide buyers with guided rather than open-ended interaction. Even with this limitation, the test confirmed that the sequence from model export, parsing, GLTF conversion, buyer interaction, and cost update could be completed successfully.

Finally, the fifth objective, evaluating performance from technical and user perspectives, revealed a mix of successes and weaknesses. The cost feedback loop was reliable, yet technical fragility remained visible in instances where geometry did not refresh, or classification mismatches disrupted calculations. Nearly one hundred test runs were required to reach stability. From a usability perspective, the simplified interface was judged clear and intuitive, but its occasional instability suggests that further refinement would be necessary before adoption in practice.

Taken together, these results show that the prototype substantially met its objectives of enabling controlled buyer interaction, providing transparent cost updates, and generating structured outputs for staged investments. However, the workflow remains fragile and dependent on professional oversight for reintegration into BIM environments.

5.2 Prototype Effectiveness in Staged Investment Models

The prototype was evaluated specifically against the staged investment model, where buyer payments are released in instalments linked to construction milestones. Testing was deliberately confined to a single element, the kitchen partition wall, to ensure clarity of results. The initial cost of this wall was €682.50 when modelled as Standard Drywall, and this figure was recalculated instantly when upgraded to Premium Drywall (€941.25) or Glass Partition (€1,342.50). Each adjustment was recorded in the Excel cost sheet, which was connected to the classification codes embedded in the IFC model.

This demonstrated that even at unit level, modifications could be priced without ambiguity and linked directly to the financial structure of staged investments. The workflow provided not only immediate cost updates but also a structured log of quantities, rates, and timestamps. Such traceability is critical in staged investment contexts where every payment must be justified and auditable.

While the prototype itself stopped at Excel exports, the workflow indicates how these files could be integrated into CDE platforms such as Autodesk Construction Cloud or Dalux. Literature confirms that such integration would allow installment schedules to be updated automatically, creating a seamless connection between buyer decisions and project financing. It must be emphasised, however, that this reintegration step was not tested within the prototype. The demonstration proved that updates could be produced in a structured and technically valid format, but the final step of synchronising them with live project records remains a task for future development.

The staged investment effectiveness of the prototype is therefore twofold. First, it established that buyer-led changes can be logged and priced transparently at the smallest scale of a single wall. Second, it confirmed that the outputs of such changes are technically compatible with staged investment workflows, even if not yet automated within a live CDE environment.

5.3 Limitations and Technical Challenges

Despite its achievements, the prototype revealed significant limitations. The most critical concerns interoperability between buyer-facing outputs and professional BIM environments. Once the IFC model was converted into GLTF for web-based editing, it became nearly impossible to regenerate a consistent IFC file from the modified GLTF version. In this study, the final usable output was a delta Excel file that could be uploaded to a CDE to adjust staged installment costs. Although professionals could manually reconstruct the IFC using these deltas, the process introduces risks of mismatched classification codes, incorrect quantities, or partial data loss. This dependence on professional rework limits the automation potential of the workflow and represents the largest gap between prototype demonstration and practical adoption.

Other limitations were technical in nature. Parsing errors in IFC.js occasionally prevented elements from displaying in the viewer, creating discrepancies between visual output and cost data. Rendering instability in Three.js meant that geometry sometimes failed to update or disappeared when modifications were applied, as observed during wall resizing tests. In addition, mismatches between classification codes in the IFC model and entries in the cost database occasionally produced incorrect unit rates or no updates at all, requiring manual correction.

The scope of validation was also narrow. Testing was confined to a single wall in one unit, which simplified the process but restricted the evaluation of scalability. Real residential projects would require dozens of elements across multiple units to be tracked simultaneously, introducing a much higher degree of complexity.

Finally, while the prototype produced Excel exports suitable for CDE upload, this integration was not carried out. The step from delta file to fully synchronised project record remains untested. Performance and reliability also posed challenges, as nearly one hundred test iterations were needed before achieving a stable outcome.

These limitations do not undermine the value of the research. Instead, they clarify the technical and organisational challenges that must be overcome in future work. The workflow is feasible at a small scale but fragile and dependent on professional oversight, particularly in its connection to BIM authoring tools and CDE.

5.4 Practical Implications for Residential Projects

The outcomes of the prototype, even within their narrow scope, offer several practical implications. For developers, the key value lies in providing buyers with immediate cost feedback that is tied directly to classification codes and staged payments. In the case study, the upgrade of a single wall finishes recalculated instalment values in seconds, demonstrating how disputes over cost changes could be reduced. This approach allows developers to handle buyer queries more efficiently and forecast cash flows with greater accuracy.

For buyers, the implication is improved trust. In the prototype, every change was visible and traceable, from the €682.50 baseline cost of Standard Drywall to the €1,342.50 total for a Glass Partition. Even though limited to one wall, this example shows how transparency can be achieved when buyers see the financial consequences of their choices instantly and in connection with staged payments. Such visibility reduces uncertainty and supports timely decision making.

For project teams, the workflow presents a structured method for capturing buyer edits. Although it cannot yet regenerate an IFC file automatically, the delta Excel output is technically suitable for CDE integration. This means that cost managers and BIM coordinators could incorporate buyer changes into existing systems without rebuilding the entire model. Professional oversight remains necessary, but the process is far more structured than conventional email or spreadsheet-based exchanges.

In practice, this implies that buyer-facing BIM tools can complement existing professional workflows rather than replace them. Developers gain efficiency, buyers gain transparency, and project teams gain structured outputs that can be validated and reintegrated with manageable effort.

5.5 Summary of the discussion

The findings of this chapter confirm that the prototype fulfilled the aims of this research in a focused but meaningful way. By testing a single editable element, the study demonstrated that classification-linked cost updates can be made transparent to buyers, recorded reliably in a cost database, and prepared for integration with staged investment schedules. The specific test of the kitchen partition wall showed cost progression from €682.50 for Standard Drywall to €941.25 for Premium Drywall and €1,342.50 for Glass Partition, providing clear evidence that cost transparency can be achieved through guided interaction.

At the same time, the study highlighted the fragility of current workflows. The inability to regenerate IFC files from GLTF edits, parsing errors, rendering instability, and classification mismatches all limited the scope and stability of testing. These issues confirm that professional oversight is still required, particularly for reintegration into BIM environments.

Nevertheless, the practical implications are significant. The research confirmed that staged investment models can be supported through structured delta exports, that buyers can be given meaningful engagement without being overwhelmed by technical tools, and that developers can improve trust and efficiency through transparent cost updates.

6 CONCLUSION AND FUTURE WORK

6.1 Conclusion

The aim of this dissertation was to explore how Building Information Modelling (BIM) can move beyond its traditional role as a coordination tool for professionals and be adapted into a direct communication medium for buyers in staged investment housing projects. The study set out to address the gap between accessible but unreliable consumer platforms and professional BIM tools that remain inaccessible to non-technical users. A prototype was developed and tested on a residential case study, showing how buyers could interact with simplified models, receive live cost updates, and link their choices directly to staged instalments. The findings confirmed that real-time cost transparency and guided buyer engagement can be achieved without compromising the integrity of professional workflows.

The unique contributions of this research can be summarised as follows:

1. Proof of concept for a buyer-facing BIM prototype that provides real-time, transparent cost feedback in staged investment settings.
2. Integration of IFC metadata, classification codes, and 5D cost data within an interactive GLTF-based model, enabling live recalculation of costs during buyer edits.
3. Demonstration of constraint-based interaction, where buyers are given control over non-structural elements while structural integrity remains protected.
4. Creation of a verifiable data bridge through structured delta exports, showing how buyer decisions can be reintegrated into professional environments and linked to staged instalment schedules.
5. Extension of BIM's role from professional coordination to buyer communication, offering a framework for strengthening trust, transparency, and participation in residential construction.

The research also revealed limitations. The prototype was tested on a single flat with a restricted range of editable elements, and the workflow relied on delta exports rather than full IFC regeneration. Technical fragility was observed during testing, which showed that stability and interoperability remain challenges. These constraints point directly to future directions, where scalability, technical refinement, and immersive buyer validation will be needed to bring the system closer to practical adoption.

In summary, this study demonstrated that BIM can serve not only as a coordination tool for professionals but also as a platform for transparent buyer engagement. By connecting design choices with cost implications and staged investment instalments in real time, the research offers a foundation for more trust-based and participatory approaches to residential construction.

6.2 Future work

The prototype demonstrated that a buyer-facing BIM system with real-time cost updates is possible, but it also highlighted clear boundaries that open directions for future research and development. These directions can be grouped into four themes.

1. Technical stability and interoperability

The workflow must be strengthened to ensure reliable handling of model data. Future work should explore more robust links between GLTF viewers, IFC schemas, and professional authoring tools, as well as stable connections with Common Data Environments. Improved error handling and consistency checks will be essential for buyer confidence.

2. Scalability and IFC regeneration

The prototype was validated on a single flat with limited editable elements. The next step is to extend the workflow to multiple units and a broader set of components, while exploring methods to regenerate or synchronise IFC models from buyer edits. Achieving this will make the approach usable at project scale.

3. Buyer testing and immersive interaction

The system should be validated with real buyers rather than in controlled trials. Usability studies are needed to test whether buyers understand the cost logic, trust the instalment recalculations, and feel more confident in their decisions. Immersive technologies such as Virtual or Augmented Reality could further enhance engagement.

4. Industry adoption and integration

For the system to be adopted in practice, it needs to align with tools already in use by developers and cost managers. Linking the prototype to commercial platforms such as BEXEL Manager or Autodesk Construction Cloud would position it as a complementary front-end, rather than a stand-alone solution. Parallel research into buyer behaviour and payment preferences could also inform how staged investment models are structured in practice.

7 REFERENCES

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