2025 European Conference on Computing in Construction

CIB W78 Conference on IT in Construction

Porto, Portugal
July 14-17, 2025

A STRUCTURED FRAMEWORK FOR CLIENT-PROFESSIONAL COLLABORATION IN RENOVATION PROJECTS USING AR/VR TECHNOLOGIES

Simone Balin[1], Giovanni Luca Laino[2], and Cecilia Maria Bolognesi[1]
[1]Politecnico di Milano, Milan, Italy
[2] Freelance, Milan, Italy

Abstract

Residential renovation projects are plagued by fragmentation, cost uncertainty, and inefficient stakeholder communication. This paper presents a structured, patent-pending framework that integrates immersive technologies (VR/AR) within a cloud-based collaborative platform to address these challenges. A real-world case study in Bologna, Italy provided insights of the frameworks capabilities and compared them based on conventional tours. The findings show design time along with real-time cost estimation was considerably a shorter process while still proving accurate. The benefits of this approach offer enhanced transparency and client buy-in, providing an improved, transparent, model, now and for the future, for renovated project management.

Introduction

Digital transformation in the renovation sector is driven by converging technological and social forces (Balali et al., 2019). This paper explores the growing demand for personalized environments coupled with technological advancements like 360-degree imaging, virtual tours, and point cloud scanning (Luis et al., 2021), while considering regulatory frameworks prioritizing resource and energy optimization (Liu et al., 2021; Nagy et al., 2021).

This study applies a scientific approach to a real case, involving a housing unit located in via Mazzini in Bologna, demonstrating how the combined application of a structured approach adopting immersive technologies can improve the efficiency of the decision-making process within the constraints of the Italian regulatory framework.

In Italy, regulations like Superbonus 110% (Legislative Decree 48/2020) and mandates for BIM adoption (Legislative Decree 560/2017), have begun to drive digital solutions into renovation. Both introduce a focus on integrating cost estimation, collaboration from stakeholders, and transparent project processes. However, the construction and renovation sectors still face challenges as they adopt traditional processes.

Fragmentation of activities and inadequate communication among key stakeholders—clients, designers, and construction companies—remain significant hurdles (Balin et al., 2023). Clients often struggle to fully understand the technical specifications of projects due to their complexity and implications for time and financial resources. This lack of transparency leads to misunderstandings, resulting in hard-to-manage delays and cost overruns, significantly undermining overall project effectiveness (Paes et al., 2017). Our integrated approach, currently under patent, combines virtual representation with transparent and direct communication via the cloud, creating an immersive environment, at different levels, where clients and professionals can collaborate in real time. The structured framework facilitates a deeper understanding of technical specifications and design decisions, providing clients with a clear and comprehensive view of costs and timelines.

The goal is to utilize virtual tools as part of the renovation process to provide a smoother and more expected user experience for all stakeholders. The construction of this framework is a meaningful step in terms of digitalization. In particular, the use of immersive technologies and real-time collaboration applications is being leveraged to resolve existing challenges, while also setting new standards of efficiency and transparency while developing a structured framework that could enhance communication between stakeholders; furthermore, it provided project managers more thorough control mechanisms over their methodology, thus improving expectation of outcomes, as well as stakeholder satisfaction (Khan et al, 2021; Sangiorgio et al, 2020). This paper is written to assess this new renovation management approach in detail. The Methodology chapter evaluates a structured framework with technical architecture focused around the innovations and parameters discussed. The Case Study chapter outlines the application of the framework through the comparative case study between this new experimental work flow and traditional workflows. The Conclusions chapter reviews the results regarding the benefits, significant issues and implications of utilizing this type of new framework for the construction sector, and looks to provide guidance on possible next steps.

Methodology

The structured framework (see Figure 1) redefines traditional renovation processes through a digital approach, integrating cloud architecture with immersive reality technologies. The latter were adopted for their ability to generate environments that overlap with the real context or are completely immersive, allowing customers to experience detailed simulations of the proposed projects depending on their needs and the project phase in which they are operating. The integration of immersive realities follows a structured approach in the different phases of the renovation process, ensuring seamless collaboration between the interested parties.
In the early design phase, VR is employed to provide an immersive visualization of the project. Clients and professionals interact with the virtual environment through head-mounted displays (HMDs) such as Meta Quest Pro or HTC Vive, allowing them to navigate the space at a 1:1 scale. This real-time interaction enables users to modify layouts, materials, and finishes dynamically, facilitating a more intuitive and informed decision-making process before finalizing design choices. Alternatively, the platform offers different levels of immersion, including classic desktop PC viewing and interaction.
During review and validation phase, AR can be integrated to overlay digital design elements onto the physical environment. Using mobile AR applications or AR headsets, stakeholders can verify spatial configurations directly on-site, ensuring consistency between digital models and real-world conditions. This approach enhances accuracy in design implementation and provides an additional layer of control before proceeding with construction.
The structured collaboration framework is supported by a cloud-based platform that serves as a central hub for project management.
Clients, designers, and contractors communicate through a shared dashboard for clients, designers, and contractors to upload, edit, and analyze 3D models in various formats (IFC, OBJ, FBX). The system includes AI-generated design solutions and dynamic cost estimates capabilities that keep shared project requirements informed by the clients' preferences. Although clients independently engage with the planning platform to design their renovation, designers and contractors, after verifying a design is feasible, engage clients to submit a bid. This iterative process creates a data-led process for planning renovations that is constantly re-evaluated and improved before design is implemented. Moreover, as we will see in the subsequent chapters, this new way of introducing renovation planning will alter the way the figures involved communicate and their relationship to the project itself.
The framework's architecture is built around five fundamental components, each playing a crucial role in streamlining the property renovation process.

In the cloud platform, users can upload property data and relevant information. They have the flexibility to independently upload a 3D scan of the space or, if needed, request the assistance of a professional technician—also registered on the platform—to handle the graphic restitution and design phases. This ensures that even users without technical expertise can access high-quality digital models of their properties.
Once all the necessary data is uploaded, users engage with the interactive dashboard. This dynamic interface synchronizes actions and variables in real time via the cloud, allowing for the generation of multiple renovation configurations based on individual needs. Within this shared environment, users can specify key details such as the type of renovation, building typology, and available budget, making the entire planning phase more structured and transparent.

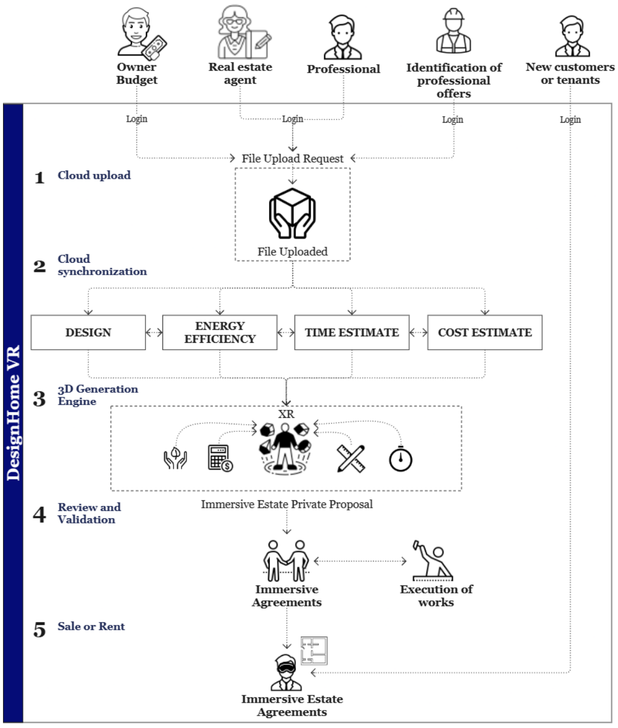

Figure 1: Functional diagram of the Design Home VR process.

At the heart of the system is the 3D engine, which recreates a detailed digital representation of the environment. This engine is enhanced by an intelligent assistant that offers personal recommendations regarding budget, style, and technical requirements. Users can then interact with the immersive interface to customize materials, layouts, and finishes, receiving real-time updates on costs and project timelines. This process not only increases transparency but also improves decision-making efficiency by providing immediate visual feedback.
A crucial aspect of the framework is immersive collaboration among clients, designers, and companies. As modifications are made, notifications ensure that all stakeholders remain informed, while integrated validation tools help streamline approvals. Designers and

contractors can access project details, submit bids based on the specified requirements, or request further clarifications. Once the final configuration is agreed upon, the selection of bidders and contract negotiations take place, leading to the official start of the renovation work.
Beyond renovation, the platform also extends its capabilities to the real estate market. If a property is intended for sale, real estate agents can leverage the system to conduct virtual property tours on behalf of their clients. This significantly reduces logistical challenges and the environmental impact of unnecessary travel, while also optimizing property selection times. Prospective buyers benefit from a highly immersive and realistic experience, allowing them to explore and evaluate spaces remotely before scheduling an in-person visit. This feature enhances the overall buying experience, providing significant advantages to clients, agents, and property owners alike. By integrating immersive visualization, advanced data analysis, and a real-time collaborative system, the framework aims to reduce discrepancies between virtual design and practical implementation, optimizing project performance and ensuring greater decision-making transparency.

Technology Infrastructure

The system architecture is based on an authentication and authorization mechanism that implements Firebase and OAuth2 services, thus ensuring access to the platform. Once the authentication process is completed, the user can interact with a centralized project that uses Firebase as a data management and storage infrastructure.
The AI Assistant is one of the main components of the system, based on GPT technology and managed by a dedicated orchestrator. These assistant processes user requests and proposes actions through a dialog interface accessible both in a virtual reality environment and via the web. The assistant communicates with the VR engine, developed in Unity, by sending commands in JSON format (see Figure 2). The platform incorporates a spatial mapping system that allows the digital three-dimensional reconstruction of environments. This process uses different detection technologies available in VR or AR devices. The technological core of the system integrates three complementary data acquisition methodologies: a depth sensor for precise measurement of distances, a high-resolution camera for the acquisition of visual details, and a LiDAR sensor for the generation of maps based on laser scans. The processing flow begins with the simultaneous acquisition of data from the three sensors, which are immediately integrated into a three-dimensional point cloud. This is then converted into a 3D mesh, optimized for precision and detail, and finally imported into the Unity development environment. The system operates in a continuous and dynamic cycle, constantly monitoring the environment and updating the digital mapping in real time (see Figure 3).
The VR engine manages visualization and interaction with the digital environment. In addition to scanning the space, it allows the import and modification of 2D and 3D floor plans, the manipulation of objects and walls, and the application of advanced editing systems. Multi-user collaboration is made possible by Photon Fusion, a real-time network engine developed by Photon Engine, which ensures synchronization between users.
In parallel with the VR environment, the system includes a web module that serves as a management interface. This module offers access to an interactive dashboard, allows the management of a virtual warehouse, and allows calendar synchronization through integration with Google APIs.

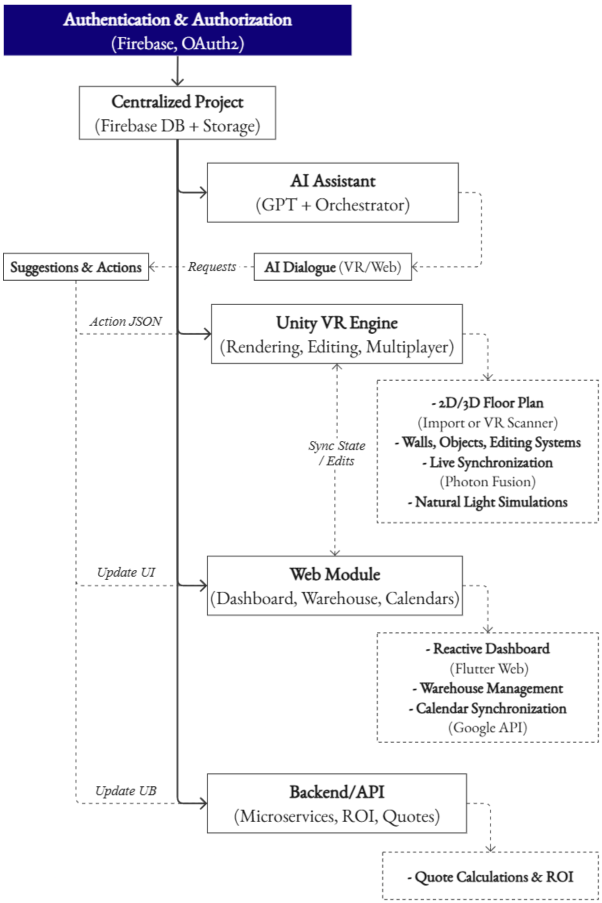

Figure 2: Logical System Map: From Authentication to Dashboard.

The system is complemented by a backend and API module that provides microservices, return on investment (ROI) calculations and quote management. This backend constantly updates the user interface with real-time data and provides financial analysis based on the simulations performed.

```
void RealTimeSpatialMapping() {
    var depthData = GetDepthSensorData();
    var cameraData = GetHighResCameraData();
    var lidarData = GetLiDARData();
    var pointCloud = MergeSensorData(depthData, cameraData, lidarData);
    CloudService.Send(pointCloud);
    var mesh3D = ConvertPointCloudToMesh(pointCloud);
    var optimizedMesh = OptimizeMesh(mesh3D);
    UnityImport(optimizedMesh);

    while (systemActive) {
        if (NewDataAvailable()) {
            var newDepthData = GetDepthSensorData();
            var newCameraData = GetHighResCameraData();
            var newLiDARData = GetLiDARData();
            var newPointCloud = MergeSensorData(newDepthData, newCameraData, newLiDARData);
            var newMesh3D = ConvertPointCloudToMesh(newPointCloud);
            optimizedMesh = OptimizeMesh(newMesh3D);
            UpdateUnityModel(optimizedMesh);
        }
        Wait(updateInterval);
    }
}
```

Figure 3: Example of Real-Time 3D Spatial Mapping Algorithm.

Case Study

The case study focused on a cozy 90 square meter apartment situated on Via Mazzini in Bologna (check out Figure 4). This property, featuring eight rooms and nestled in a residential neighborhood, was up for sale. The real estate investors involved were keen on assessing the purchase and planning a renovation with the goal of renting it out. Since this was a real-life scenario, it was crucial to team up with various professionals to ensure everything ran smoothly and efficiently:

- Clients: eager to buy and renovate the property for rental. - Real estate agent: in charge of showing and selling the apartment.
- Architect: tasked with the design and cost estimation.
- Two specialized companies: responsible for carrying out the renovations and managing the overall project.

Initially, the apartment was listed with standard paper floor plans and a handful of photos, which didn't quite capture its full potential. To help the investors with their planning, they turned to DesignHome VR, allowing them to design the spaces themselves and visualize how the renovation would turn out. The goal was to create three separate rooms, each with its own private bathroom, and to include a functional kitchen in one of them. After identifying all the key players and outlining the case study, a comparative analysis was performed using both traditional methods and this new structured approach.

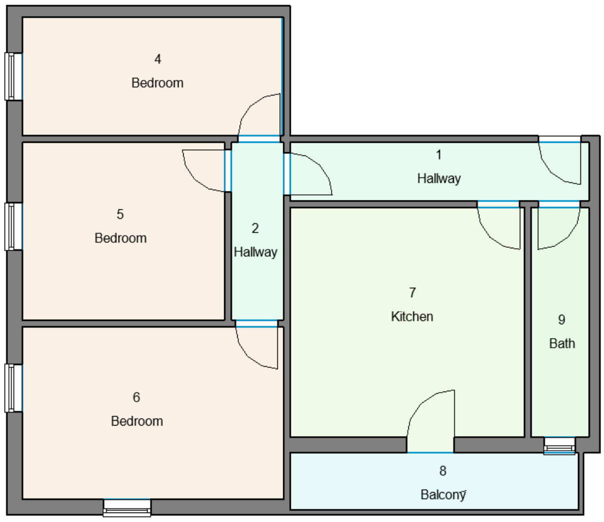

Figure 4: Plan of the apartment chosen as a study case, before the restructuring intervention.

Simulation with Traditional Method

The property was presented to clients through static two-dimensional floor plans and a set of photographs. Clients were able to conduct an on-site visit arranged by the real estate agency. This process required a significant time investment from both the client and the agency, providing only a basic understanding of the space. However, the 2D representation and photographs failed to effectively convey the property's transformative potential, limiting the client's ability to envision modifications or optimizations. To configure the layout, clients relied on the assistance of an architect to develop a revised project. The architect prepared floor plans and renderings of possible solutions, a process that involved extended timeframes and additional costs for every iteration or adjustment requested by the clients. This made the process inflexible and expensive, leading to substantial delays compared to the original schedule.

Once the layout was defined, clients had to allocate additional time to find companies and suppliers to carry out the work. After identifying a contractor, on-site inspections were conducted to compensate for the lack of detailed photos and floor plans. This led to slow cost estimations, prone to discrepancies between initial estimates and final actual costs. The whole process has been schematized in figure 5. Unlike the traditional method, which lacks immersive visualization and real-time interaction tools, the new system integrates immersive technologies and shared environments for improved collaboration. By allowing customers to experience the design in a realistic and interactive way, they can communicate and make decisions more effectively. In addition, the use of immersive-collaborative tools allows stakeholders to visualize and manipulate the design together, improving process continuity and increasing decision-making efficiency.

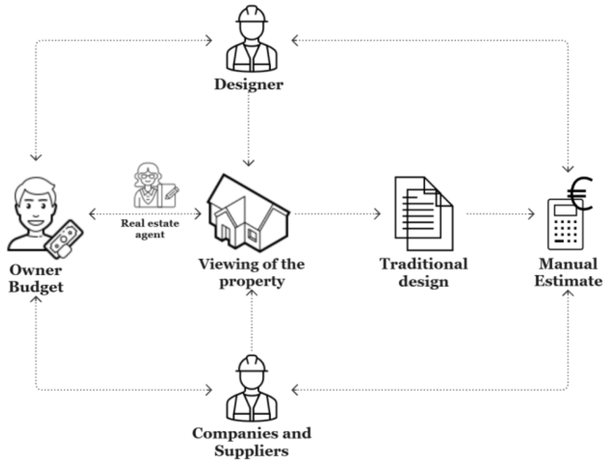

Figure 5: Traditional method of design and cost estimation for building renovations.

Simulation Using DesignHome VR

With the new framework, the design and renovation process were redefined, allowing clients to manage the initial phases and involve stakeholders only later. This approach gave property owners more control over the entire process, from design to sale (see figure 6).

In the case study analyzed, the client independently started the design phase by uploading the data and scanning the apartment.

Due to this framework, he was able to create a high-fidelity 3D model of the property with the help of a Meta Quest 3 viewer. This enabled us to digitize the apartment in great detail, which would serve the design with accuracy. Alternatively, customers may provide their own floor plans in PDF, CAD or 3D (e.g., IFC, OBJ, FBX) format or order the assistance of an architect or engineer through the platform to model it by hand. Within the immersive environment, the team of investors, who represented the client, started to arrange the spaces in line with their particular requirements and aims. The primary goal was to convert the real estate unit into three separate rooms with a personal bathroom, having a functional kitchen in the living room and a central corridor to maximize movements. The interactive system allowed him to experiment with various layouts, modify the location of the walls and make on-the-fly choices of finishes and materials. The platform ensured that they would receive instant feedback on the design decisions and could therefore check whether they adhered to the functional and aesthetic limitations without having to go back and forth with designers. The platform was automatically estimating the project, where the costs were changing in real time concerning the changes. Customers were also provided with a simplified version to refer to quickly, as well as a technical specification, with all the information about the materials and work requirements at the end of the process. Following the autonomous design phase, the client added a technician to deal with the bureaucratic part and a company to check and validate the cost estimates. Thanks to the platform, the engineer and the contractor were able to examine the project, verify the structural and plant feasibility with a single on-site inspection and confirm the validity of the project and the estimated costs, with only slight variations due to the necessary movement of the plants.

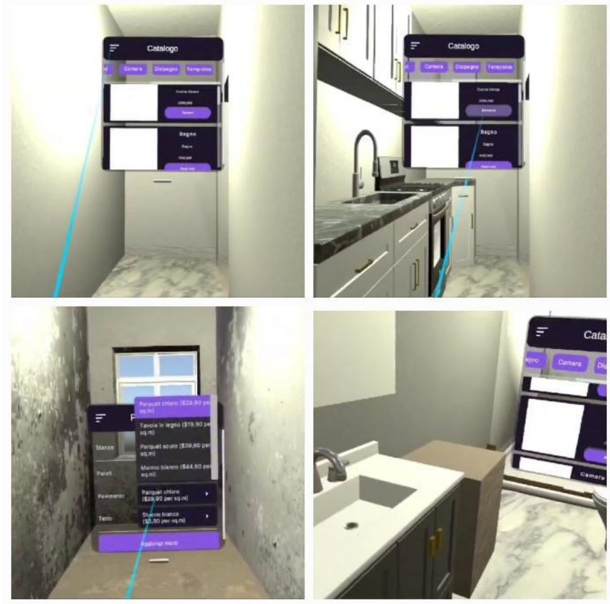

Figure 6: The four images illustrate the DesignHomeVR application applied to the case study. The image at the top left shows the space designated for the new kitchen with its updated finishes, while the adjacent image on the right represents the placement of the corresponding furniture. In the lower section, the image on the left shows the bathroom before the renovation, while the one on the right depicts the renovated bathroom after the refurbishment.

In this phase, augmented reality (AR) was used to superimpose the digital model onto the real environment via tablets. This was achieved through marker-based tracking and spatial anchoring, ensuring alignment between virtual and physical elements. As a result, it enabled verification of the correspondence between the design and the current state of the building, reducing the risk of superposition errors and inconsistencies.

Then, the 3D model and the related detailed cost estimate were published, allowing the construction companies to review the specifications, propose any technical changes and submit offers before the start of the work.

Thanks to the clarity of the plan, the work began without delays or uncertainties. At the end of the renovation, the owner entrusted the rental of the property to a real estate agent who, through this structured framework, organized virtual visits for potential tenants.

They were able to explore the apartment remotely, evaluating the spaces and finishing without the need for physical inspections. A key element of the framework is its cloud-based collaborative environment, which acts as a central hub for project management (see figure 7). Clients, technicians, designers and contractors can interact through a single-shared platform, where the 3D model is stored and updated in real time. The system allows you to manage access levels for each professional figure, ensuring a structured and efficient workflow.

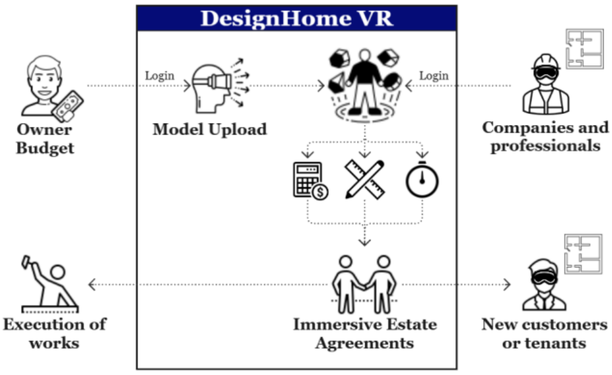

Figure 7. Structured approach used in the simulation with Design Home VR.

Conclusions

The case study demonstrated the effectiveness of this approach as a tool for assisted real estate design (table 1). Completed in just 2-3 days, the project significantly reduced the time compared to the 10-15 days required by the traditional method. The accuracy of the estimate was equivalent, with a margin deviation of 5%; however, the real-time generation process offered by the structured framework eliminated the need for manual calculations, simplifying and accelerating the operational flow.
The virtual reality simulation allowed customers to explore and modify the project in real time, overcoming the limitations of static renderings and physical visits. Another distinctive aspect was the transparency on costs, guaranteed by the immediate and detailed production of the estimate in an immersive environment, which reduced the uncertainties typical of the traditional method.

Table 1: Comparison between the Traditional Approach and the Structured Framework with Design Home VR.

Aspect	Traditional Method	Structured Framework
Design Time	10-15 days	2-3 days
Estimate Accuracy	5%, requires manual intervention	5%, real-time
User Experience	Static renderings and physical visits	Immersive and interactive simulation
Cost Transparency	Requires additional explanations	Detailed and immediate
Client Involvement	Limited to feedback on design proposals	Active participation in the design process
Overall Cost	High due to renderings and consultations	Reduced, with integrated tools

Customers were not just passive observers; they actively engaged in the design process, which allowed them to shape the project and enhance their overall experience. This approach also managed to cut out extra costs associated with renderings and outside consultants, making it a budget-friendly option. These outcomes really showcase how this innovative method can transform real estate design and renovation, making the whole process more efficient and enjoyable.

Current Limitations

Despite the promising outcome of our designed framework, we have revealed several important limitations that might interfere with the extent of the generalizability of the findings and the stability of the system. Our approach that relies on the single case study is merely a point of departure and constrains us in making generalized conclusions. According to Nikolić & Whyte (2021), research into VR implementation requires a wide variety of samples across various contexts to draw any concrete conclusions. The 3D generation engine with a built-in assistant, which makes the third part of our approach, presents a set of challenges on its own. Though the assistant could provide individual guidance concerning the budget, style, and technical requirements, it cannot match the knowledge about the peculiarities of architecture. It aligns with the results of Kwame et al. (2024), who observed the same drawbacks in AI-based design systems. Even though the assistant can indeed bring more transparency and aid the decision making process, it can do so mostly in relatively standard design cases. Automated estimation system although having 5 percent accuracy rate like conventional techniques has some major drawbacks (see figure 8). Its correctness is greatly dependent on the completeness and the currency of its database. Now it has problems in regional price differences and local market circumstances. The same limitations apply to automated estimation systems as (Liang et al., 2022) stated that even advanced algorithms cannot consider microeconomic differences in various geographical areas.
Additionally, these cost estimates reflect current market conditions but lack predictive models for long-term projects, potentially leading to discrepancies between initial estimates and actual implementation costs. Another critical factor is the real-time synchronization between the Unity module, the cloud infrastructure and the different dashboards used by users: when the number of simultaneous connections grows, latency can increase, compromising the fluidity of the shared experience.
Another critical aspect concerns users' perception of the virtual environment. The results indicate significant variation in spatial and design comprehension depending on age and prior experience in the construction sector. Comparative studies conducted by (Ventura et al., 2020) suggest that familiarity with digital tools can influence the ability to navigate and interpret complex virtual environments. However, in the context of DesignHome VR, this perceptual heterogeneity could compromise the

uniformity of the user experience and require further system optimizations to improve accessibility.

No.	Description	Unit	Quantity	Unit Price (€)	Total (€)
11	**Possible supply and installation of a suspended ceiling** in plasterboard, fixed to self-supporting metal frames made of galvanized steel sheet profiles with a thickness of 6/10 mm and a spacing of 600 mm. Includes joint sealing, finishing works, protections, and everything necessary to deliver the finished work.	sqm	90.00	90.00	8100.00
12	**Pre-mixed base plaster for interior and exterior use** made of pure natural hydraulic lime NHL 3.5, compliant with UNI EN 459-1 standards, with high breathability for hygroscopic properties, fire reaction class A1. Applied manually on hollow bricks with a thickness of 2 cm, leveled, and finished. **Bathroom - Kitchen** (where the previous covering is removed) + new partitions + installation modifications	sqm	102.00	45.00	4,590.00
13	**Pre-mixed screed** made of lightweight expanded clay with water-repellent properties (moisture absorption of approximately 1% to 30 minutes according to UNI EN 13055-1), with specific binders and additives, for **underlayment finishing screeds** for insulation and leveling. Work performed and leveled, with a thickness of 5 cm.	sqm	90.00	40.00	3,600.00
14	**Lightweight fill of ISOCAL type**, made of expanded polystyrene beads or Leca, for filling and covering technological installations.	per unit	1.00	2,800.00	2,800.00
15	**Smoothing of non-plastered walls**, performed with a layer of gypsum-based plaster and applied with an American trowel.	sqm	270.00	16.00	4,320.00

Figure 8: Excerpt from the estimated metric calculation after the modifications made in the immersive environment.

Although the system enables significant user autonomy, it cannot eliminate the need for professional supervision. Complex projects require external technical validation concerning structural integrity, regulatory compliance, and adherence to construction practices. This limitation reflects broader challenges in automated design systems identified by (Saka et al., 2023), who argue that human-AI collaborative models remain essential in architectural applications with significant real-world consequences.

Another aspect to consider is the perceptual variation among users, due to the possibility of using the platform with traditional or advanced immersive modes. The perceptual discrepancy that can emerge between a traditional visualization and an advanced immersive experience represents a topic that deserves further investigation and future studies.

Another limitation concerns privacy aspects. The inclusion of photos or 3D scans of properties, which may include personal or sensitive details, raises issues regarding data management and confidentiality (see figure 9). Images and scans may contain identifying information or elements that reveal private aspects of users or property owners. Unauthorized publication on digital platforms or sharing with third parties may violate personal data protection regulations, such as the GDPR (Lee et al., 2021; Yu et al., 2022). Therefore, implementing procedures for data anonymization and obtaining explicit consent is essential to ensure regulatory compliance and the protection of users' rights.

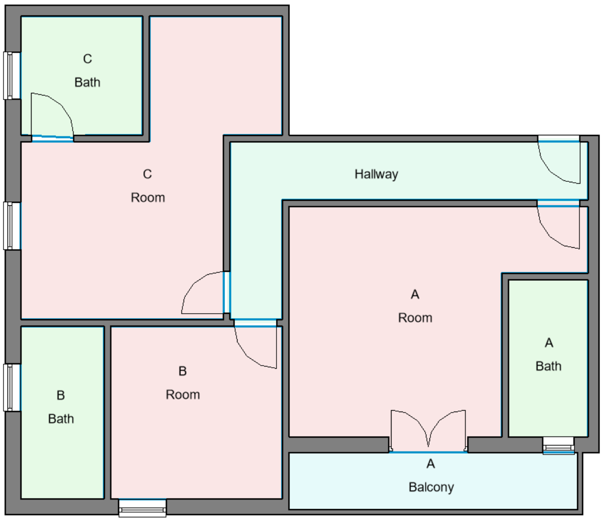

Figure 9: Plan of the apartment chosen as a study case, after the restructuring intervention.

Future Developments

To address current limitations, future research on this approach will focus on exploring several strategic areas. The expansion of the research sample, including a wider variety of building typologies and design objectives, will be explored.

Research efforts will be directed towards optimizing algorithms to handle more complex projects, while exploring open-source approaches to improve technological accessibility, with potential cost reductions and the development of simplified versions of the platform. In the area of privacy and security, possible implementations of automatic anonymization systems for images and 3D scans will be analyzed, along with experimental modules for informed consent management. The investigations will extend to emerging technologies such as blockchain and zero-trust encryption models for data protection.

In parallel, we will try to develop functionalities to verify compliance with local building regulations.

User experience research will be directed at the study of virtual assistants capable of supporting decisions in real time. We will also investigate software adjustments that can reduce resource consumption and improve performance in complicated scenarios, or experimental and pitch in tools that can improve communication between all of the various parties involved in the process.

Regarding cost estimation, we will consider possible connections with open-data platforms to reduce our dependence on proprietary databases.

Research will also focus on localized databases with regional modifiers and on the application of AI-based predictive models and time series, aiming to obtain more accurate estimates and updates based on market trends. With these improvements, this innovative structured approach aims to democratize building design, making it more accessible, efficient and transparent for an increasingly wider audience.

Acknowledgements

This research was inspired by the collaboration with Giovanni Luca Laino & Andrea Laino (creators) from their innovative approach to the development of the DesignHome VR platform, currently in the process of patent registration. I would also like to express my gratitude to Matteo Morvillo (researcher and developer) for his willingness to share insights and technical expertise, which were instrumental in shaping the framework and methodology proposed in this study. Additionally, I extend my thanks to Simone Balin for his literature analysis, project contributions, and writing assistance, which significantly enhanced the quality and depth of this research.

References

Balali, V., Zalavadia, A., & Heydarian, A. (2019). Real-Time Interaction and Cost Estimating within Immersive Virtual Environments. *Journal of Construction Engineering and Management*, *146*(2), 04019098. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001752

Balin, S., Bolognesi, C. M., & Borin, P. (2023). Integration of Immersive Approaches for Collaborative Processes with Building Information Modeling (BIM) Methodology for the AEC Industry: An Analysis of the Current State and Future Challenges. *Virtual Worlds 2023, Vol. 2, Pages 374-395*, *2*(4), 374–395. https://doi.org/10.3390/VIRTUALWORLDS2040022

Khan, A., Sepasgozar, S., Liu, T., & Yu, R. (2021). Integration of BIM and Immersive Technologies for AEC: A Scientometric-SWOT Analysis and Critical Content Review. *Buildings 2021, Vol. 11, Page 126*, *11*(3), 126. https://doi.org/10.3390/BUILDINGS11030126

Kwame, A. G., Nawaz, M., Al Naqbi, H., Bahroun, Z., & Ahmed, V. (2024). Enhancing Work Productivity through Generative Artificial Intelligence: A Comprehensive Literature Review. *Sustainability 2024, Vol. 16, Page 1166*, *16*(3), 1166. https://doi.org/10.3390/SU16031166

Lee, L.-H., Braud, T., Zhou, P., Wang, L., Xu, D., Lin, Z., Kumar, A., Bermejo, C., & Hui, P. (2021). *All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda*. https://doi.org/10.48550/arxiv.2110.05352

Liang, P., Bommasani, R., Lee, T., Tsipras, D., Soylu, D., Yasunaga, M., Zhang, Y., Narayanan, D., Wu, Y., Kumar, A., Newman, B., Yuan, B., Yan, B., Zhang, C., Cosgrove, C., Manning, C. D., Ré, C., Acosta-Navas, D., Hudson, D. A., … Koreeda, Y. (2022). Holistic Evaluation of Language Models. *Annals of the New York Academy of Sciences*, *1525*(1), 140–146. https://doi.org/10.1111/nyas.15007

Liu, Z., Chi, Z., Osmani, M., & Demian, P. (2021). Blockchain and building information management (Bim) for sustainable building development within the context of smart cities. *Sustainability (Switzerland)*, *13*(4), 1–17. https://doi.org/10.3390/SU13042090

Luis, Q. N., Alisson, R. L., & de la Torre, S. J. (2021). Viability of Virtual Reality (VR) and Augmented Reality (AR) in pre-sale of multi-family projects as a strategy for better decision-making in times of change | Viabilidad de VR (Realidad Virtual) y AR (Realidad Aumentada) en la preventa de proyectos multi. *Proceedings of the LACCEI International Multi-Conference for Engineering, Education and Technology*, *2021-July*. https://doi.org/10.18687/LACCEI2021.1.1.356

Nagy, O., Papp, I., & Szabó, R. Z. (2021). Construction 4.0 Organisational Level Challenges and Solutions. *Sustainability 2021, Vol. 13, Page 12321*, *13*(21), 12321. https://doi.org/10.3390/SU132112321

Nikolić, D., & Whyte, J. (2021). Visualizing a new sustainable world: Toward the next generation of virtual reality in the built environment. *Buildings*, *11*(11). https://doi.org/10.3390/BUILDINGS11110546

Paes, D., Arantes, E., & Irizarry, J. (2017). Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems. *Automation in Construction*, *84*, 292–303. https://doi.org/10.1016/J.AUTCON.2017.09.016

Saka, A. B., Oyedele, L. O., Akanbi, L. A., Ganiyu, S. A., Chan, D. W. M., & Bello, S. A. (2023). Conversational artificial intelligence in the AEC industry: A review of present status, challenges and opportunities. *Advanced Engineering Informatics*, *55*, 101869. https://doi.org/10.1016/J.AEI.2022.101869

Sangiorgio, V., Silvia, M., & Fatiguso, F. (2020). Augmented Reality to Support Multi-Criteria Decision Making in Building Retrofitting. *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, *2020-October*, 760–765. https://doi.org/10.1109/SMC42975.2020.9283420

Ventura, S. M., Castronovo, F., & Ciribini, A. L. C. (2020). A design review session protocol for the implementation of immersive virtual reality in usability-focused analysis. *Journal of Information Technology in Construction*, *25*, 233–253. https://doi.org/10.36680/j.itcon.2020.014

Yu, R., Gu, N., Lee, G., & Khan, A. (2022). A Systematic Review of Architectural Design Collaboration in Immersive Virtual Environments. *Designs 2022, Vol. 6, Page 93*, *6*(5), 93. https://doi.org/10.3390/DESIGNS6050093