# A Comprehensive Review of Interactive 3D Visualization Techniques for Enhanced Space Planning and Decision-Making from 2D Floor Plans

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**Abstract**

The transformation of 2D architectural floor plans into interactive 3D models forms an important part of the modern design and visualization workflows, particularly for architecture, interior design, and estate agency uses. This paper introduces a general approach to automate the conversion process based on the combination of deep learning algorithms, image-processing techniques, and object detection models. On the other hand, to capture architecturally necessary features like walls, doors, windows, and other structural elements needed for such a 2D floor plan, an interior space 3D model generation is very effective and well accurate and scalable, thanks to advanced VR technologies, where users can interactively explore and modify virtual environments, and are therefore a better way for enhanced spatial understanding and design flexibility. The proposed solution addresses the main drawbacks of conventional manual methods being very labor-intensive and prone to errors by significantly reducing human intervention and expediting the model-building process. The ability to transition seamlessly from 2D plans to immersion in 3D environments opens entirely new possibilities for design iterations in the early stages, client presentations, and real-time space planning. This system maximizes the effectiveness and accuracy of architectural modeling while providing, at the same time, a robust base for immersion in virtual reality, making it a must-have tool for professionals seeking to optimize their design workflows and enhance user engagement.

## 1 Introduction

One of the real breakthroughs in architectural design and in the field of interactive 3D visualization is that 2D floor plans can now be transformed into detailed, highly interactive 3D models. This approach bridges conventional architectural blueprints with the possibility of realistic and immersive visualizations, thereby making it easier for clients, architects, and designers to better communicate, explore, and fine-tune their ideas before construction can take place. These instruments achieve an exemplary grade of precision and personalization by changing the configuration of a space from a planar, two-dimensional arrangement to three-dimensional representation [1].

Traditionally, interior and architectural design were based on 2D floor plans; they were useful for basic spatial planning but woefully lacking in conveying a full sense of scale, proportion, and spatial relationships [5].

Clients are probably unable to conceptualize and envision the three-dimensional final design, which leads to miscommunication, very expensive alternations, or delays in site work. Due to the nature of two-dimensional presentations, it does not establish the dynamic and changing character of physical environments, and as such, even the residents and professionals cannot fully comprehend what the ramifications of their design decisions will be [6]. With rapid change in the direction of technology toward gaming, entertainment, and e-commerce, new expectations of interactivity and personalization are now reaching those boundaries. This phenomenon has especially come into the open within the fields of interior design and architecture, where demand is escalating for interactive, photo-realistic, and personalized visualizations of space. Advanced tools that will translate 2D plans into living, breathing interactive 3D environments are developed to meet new expectations and be competitive in today's marketplace [4].

Received : 17 November 2024
Revised : 23 November 2024
Accepted : 08 December 2024

### 1.1 The Need for Interactive 3D Tools

Traditional static 2D plans rarely provide the level of detail that such an environment requires to be planned accurately. Modern homeowners, architects, and designers are increasingly looking towards interactive 3D tools that can provide real-time lifelike visualization, with which one can view and compare various room layouts or furniture arrangements and other design elements [5]. This interactive process helps users provide the proper design decisions; the interaction among them and clients reduces the demand for expensive changes. Real-time feedback provided by 3D models completely eliminates guesswork, which is often associated with 2D plans; this means that design intentions remain crystal clear and aligned with the vision of the client [7].

### 1.2 Leveraging Virtual Reality for Immersive Experiences

Incorporating the VR technology greatly enriches and increases the overall user experience, allowing them to fully immerse themselves in an interactive and realistic model of their design ideas. Users can use VR to walk through a virtual space, allowing them to get an in vivo experience of the different spatial fields as if one were actually there. This very immersive experience goes a long way to enable users to grasp crucial aspects such as the spatial flow, placement of furniture, and aesthetic choices made [6]. This translates into the final aspects of informed and thoughtful design choices that really take on a better appreciation of what it is that one has created. Virtual reality allows users to explore various lighting conditions, materials, and textures through the preview of their envisioned final product. As such, in enabling this exceptional degree of interactivity and realism to the users, virtual reality plays an indispensable role in drastically bridging the chasm that usually exists between the conceptual design stage and the actual construction process, and thereby enhances the design process at its core [1].

### 1.3 Remote Collaboration in the Global Design Industry

In this direction, more and more design and construction industries around the globe have been in need of digital collaboration tools that are silent. Interactive 3D tools equipped with real-time collaboration features allow simultaneous work on a design project by multiple stakeholders, regardless of where these stakeholders sit geographically [9]. With a minimal generation time, it allows the clients to view, edit, and comment on designs with little possibility of letting any communication error go into unproductivity and ensure fruitful and quick decision-making. Additionally, the functionalities of cloud-based storage and sharing do make workflow enhancement very easy so that the effective collaboration among individuals in any two locations becomes better. The capability to work at a distance is highly important today, in such an industrialized world, where quick communication and decision-making are an essential pre-condition for the success of projects [7].

### 1.4 Sustainability and Cost Efficiency in Design

Sustainability is no longer a secondary concern in the modern world of construction and design. Interactive 3D tools have played a very important role in this respect with regards to the reduction of waste and environmental impact [2]. Digital exploration and amendment of designs by clients as well as designers decrease the requirement for physical mock-ups and prototypes, thereby reducing material waste at lower levels [3]. Design errors and spatial inefficiencies can be resolved earlier in the design process when costly revisions and delays in construction would occur at a critical point of investment. Perfect detail and clarity about the final space before work break out on-site ensure a more reliable flow with fewer on-site interruptions and overall less expenditure.

In summary, this paper presents the concept of interactive three-dimensional visualization tools as a solution for turning two-dimensional floor plans into dynamic three-dimensional models. The embedding of virtual reality and real-time rendering technologies in these tools makes the process immersed and intuitive. Better communication between clients and professionals in such a scenario would minimize the costly revision process and add efficiency to the overall design project. Indeed, as the business moves steadily into a more digital future, one must recognize that interactive 3D tools will strongly influence how spaces can be visualized and animated [8].

## 2 Literature Survey

Transforming 2D floor plans into interactive 3D models has raised much interest in the last couple of years. A variety of proposals have been given through various approaches toward a solution to this problem. Different techniques, such as deep learning, object detection, and image processing, have been used in these attempts. The following section reviews some of the key contributions related to the field.

Park and Kim [1] proposed a new system called *3DPlanNet*, transforming 2D raster floor plan images into structured, vector-based 3D models. The proposed system is a hybrid model combining rule-based approaches with the power of deep learning techniques to tackle the case of very limited training data. This is done by using CNN for segmentation and post-processing heuristics to be applied. With the use of only 30 images of training data, the system manages to correctly detect walls in over 95% accuracy cases. It divides walls, doors, and windows into layers in order to produce very high-resolution models which are perfectly suited for use in Virtual Reality applications.

Another widely used technique is the *3-Phase Recognition* Method developed by Zhang et al.[2]. The pseudo-3D models are obtained from the given 2D architectural drawings in three phases. Phase 1 features are recognized with the aid of image processing techniques-edge detection and Hough transforms. These identified features are then stored in an XML for compatibility with other tools, which happens in phase 2. The third and final phase uses the Irrlicht game engine in creating interactive 3D models. In this approach, it is easier and more efficient as compared to the way it is usually done traditionally through modeling, which is usual when done manually and takes a lot of time.

In the medical field, a study conducted by Rao et al. [3] focuses on transforming 2D CT scans and MRIs into 3D models. Using techniques like Delaunay triangulation, surface reconstruction, and Laplacian smoothing, the researchers were able to create detailed, interactive 3D models. These models have numerous applications, including aiding in surgical planning and enhancing medical education by providing an interactive way to explore anatomical structures.

A comparison of four neural network-based methods for creating 3D models from 2D plans was conducted by Li et al. [4]. The methods evaluated include One-2-3-45, CRM, Instant Mesh, and Image-to-Mesh, each using different deep learning approaches, such as convolutional networks and generative adversarial networks (GANs). These methods excel in producing geometrically accurate and visually detailed models, reducing design time and improving architectural visualization.

Kim [5] explored the automatic extraction of building components from 2D floor plans using deep learning. The study emphasized the use of CNNs to detect walls, doors, rooms, and junctions from floor plans, comparing the performance of manual versus automatic extraction. The research concluded that automatic methods, particularly when compared using Analytical Hierarchy Process (AHP), outperform manual extraction, making them suitable for real-time smart building applications.

Gerstweiler et al. [6] developed a system that automates the extraction of structural and semantic data from CAD-based 2D floor plans. The system identifies key architectural elements such as walls, doors, and windows and converts them into 3D meshes. These meshes are suitable for VR applications like real estate tours, allowing users to interact with virtual environments by adjusting textures and exploring layouts.

Fréville et al. [7] introduced a framework for generating automated VR environments from 2D architectural floor plans using object detection techniques. Their system incorporates YOLOv5 to detect and classify elements such as doors and windows. It also utilizes a custom dataset generator to create synthetic floor plans for training purposes. By integrating with Unreal Engine, the system can produce VR environments that are ideal for training simulations and architectural visualization.

In [8], George and Smith proposed a semi-automated approach for converting 2D floor plans into 3D virtual models. Using tools like AutoCAD and 3D Studio Max, the researchers were able to minimize manual input, accelerating the wall extrusion and object placement processes. The models were exported in VRML 2.0 format, compatible with various VR systems, making the process more efficient for architectural design previews.

Barreiro and López [9] presented a deep learning pipeline for reconstructing semantic 3D models from 2D floor plans. The system used Faster-RCNN for detecting symbols like doors and windows, combined with Feature Pyramid Networks (FPN) for segmenting walls. By applying data augmentation techniques, such as random rotations and sliding windows, the model achieved state-of-the-art results on the CubiCasa5k dataset, outperforming previous methods in both segmentation and vectorization accuracy.

Vidanapathirana et al. [10] designed *Plan2Scene* for synthesize 3D scenes from floor plans. This technique exploits structural information of floor plans by synthesizing texture using associate photographs. Combining all the realism from structural accuracy and all the details captured in photographs, this technique overcomes these problems as in the earlier approaches, like unrealistic placement of objects and unsatisfactory textures. It, therefore, produces aesthetically pleasing 3D models and is widely applied in both architecture and virtual reality.

Overall, these studies highlight the techniques of 2D to 3D transformation where advanced integration of deep learning with visualization techniques play an important role. The automation of the process along with rapidly increasing accessibility to VR environments is driving innovation in real-estate and smart building design applications, among others.

# 3 Design

## 3.1 2D to 3D Conversion Algorithms

The conversion of traditional 2D floor plans into 3D visualization models has gained significant traction in research, leading to various algorithms aimed at improving accuracy and efficiency. One notable method is 3DPlanNet, developed by Park and Kim [1], which combines traditional rule-based methods with deep learning techniques, achieving over 95% accuracy in wall detection. This high level of precision is particularly advantageous for creating detailed models suitable for Virtual Reality (VR) applications. Another important contribution is by Rao et al. [3], who transformed 2D CT scans and MRIs into interactive 3D models using techniques such as Delaunay triangulation and surface reconstruction. Their method enhances surgical planning and medical education by providing detailed visualizations. Additionally, Barreiro and López [9] presented a deep learning pipeline utilizing Faster-RCNN for object detection and Feature Pyramid Networks (FPN) for segmentation, achieving state-of-the-art results on the CubiCasa5k dataset. This approach highlights exceptional performance in accuracy and detail in reconstructing semantic 3D models. Lastly, the Plan2Scene study [10] proposed an innovative framework that combines structural accuracy with texture synthesis to generate visually appealing 3D models, addressing challenges such as unrealistic object placement. Collectively, these contributions showcase the diverse methodologies and underline the potential for further innovation and application, particularly in enhancing architectural visualization and improving model generation accuracy.

## 3.2 Integration to VR

Recent advancements in integrating 2D to 3D conversion technologies with Virtual Reality (VR) have significantly enhanced architectural visualization. Fréville et al. [7] introduced a framework utilizing YOLOv5 for object detection, allowing for the automated creation of VR environments from 2D floor plans. Their system detects and classifies elements like doors and windows with high accuracy, resulting in immersive models suitable for training simulations. The incorporation of Unreal Engine further enhances user interaction, providing a more intuitive understanding of spatial layouts.

Gerstweiler et al. [6] focused on automating the extraction of structural data from CAD-based 2D floor plans, converting essential components into interactive 3D models. This automation reduces manual workload and is ideal for real estate tours. Meanwhile, George and Smith [8] proposed a semi-automated approach that uses AutoCAD and 3D Studio Max, streamlining the modeling process and ensuring compatibility with various VR systems through VRML 2.0 format exports. Collectively, these studies showcase the transformative potential of integrating 2D to 3D conversion with VR, enhancing both design efficiency and user experience.

# 4 Discussion

## 4.1 Existing Systems and Limitations

Despite advancements in converting 2D floor plans to 3D models, current systems face significant challenges. Many traditional methods rely heavily on manual input, leading to time-consuming processes and potential errors. For instance, CAD tools often require extensive manual adjustments for tasks like wall extrusion, resulting in 3D visualizations that may lack detail and realism, especially in capturing complex architectural features [1].

Additionally, training deep learning models typically necessitates large datasets, which can be difficult to obtain. While the *3DPlanNet* by Park and Kim demonstrates impressive accuracy with only 30 training images, such efficient models are not yet widely implemented in the industry [1].

Recent innovations aim to address these limitations. Kim's research on automatic component extraction utilizes deep learning to improve 3D accuracy while reducing manual effort [5]. Similarly, Gerstweiler et al. streamline data extraction from CAD plans [6], and Fréville et al. enhance object detection to reduce manual modeling reliance [7]. Furthermore, Barreiro and López employ data augmentation to improve model generalization across diverse floor plans [9]. By adopting these cutting-edge approaches, future systems can significantly boost the efficiency and accuracy of converting 2D floor plans into immersive 3D models, enabling more practical applications in the field.

### 4.2 Opportunities for New Innovations

Current methods are progressing, but novel additions are required. Techniques could include the addition of generative AI. This could be through diffusion models or GANs that enhance the generation of 3D models. They could automatically manufacture textures and geometry, filling gaps left by traditional systems to make models more complete with realism and detail [4].

Hybrid approaches combining rule-based systems and neural networks also open up an interesting opportunity: symbolic AI forces architectural rules while the neural networks better handle complex spatial recognition tasks. This combination enhances both accuracy and interpretability of automated systems [1].

Real-time adaptive learning systems are the new frontier. These systems refine performance based on feedback loops generated from user interactions. Generalization is also better across different architectural styles and layouts, even with a small amount of training data [5].

Edge computing and distributed architectures can improve scalability in larger projects. Relegating complicated processes to edge devices or distributed nodes makes real-time generation and rendering of 3D models more possible in resource-constrained environments [7].

Several standardized benchmarks for 2D-to-3D conversion systems have been developed. Metrics such as geometric fidelity, texturing accuracy, computational efficiency, and user satisfaction make direct comparisons possible and explain how well these systems work in detail [10].

### 4.3 Future Directions

There is much scope in the future to expand the datasets and include diverse styles of architecture for more robust models [9]. Besides, there is potential to collaborate with industries like gaming and urban planning for innovative cross-domain solutions [6]. The access will be improved by developing user-friendly interfaces and affordable systems to encourage a widespread adoption in professional as well as consumer markets [7].

Challenges facing all of these possibilities will take the field more towards fully automated, highly accurate, and accessible means for the conversion of 2D floor plans to complete immersive 3D environments [1]. Innovations in architectural visualization and related disciplines are most definitely going to be fueled by these [10].

## 5 Results

The literature survey indicates important progress in the translation of 2D floor plans into 3D models. It focuses on accuracy, automation, interactivity, and sustainability. Approaches such as 3DPlanNet [1] using deep learning techniques demonstrated very high accuracy in feature detection, ensuring wall detection with rates above 95% and efficient spatial segmentation. Automation approaches such as the three-phase recognition method [2] have streamlined the transition process, saving time and manual efforts.

Interactive tools and immersive technologies such as VR-based systems [6] enable users to explore and manipulate 3D spaces in real-time. Such tools can be integrated to intensify decision-making and engagement. Methods such as Plan2Scene [10] add texture synthesis using structural data and correct projection errors to give more realistic models.

Using a digital-first approach has saved material in the form of eliminating the need for building actual physical prototypes [3], which aids sustainable design practices. Comparative studies [4] also show that the neural networks balance the geometric fidelity and computational efficiency, bringing further advancement into the field.

In general, such developments can bring revolutionary changes with 2D-to-3D modeling tools, useful for various applications ranging from architectural visualizations to immersive training environments.

## 6 Conclusion

In conclusion, the changing world of 2D floor plans transformed into highly immersive 3D models has made much progress by a variety of innovative methods-from traditional techniques with cutting-edge technology. This kind of survey is presented as amplifying the strengths and limitations of existing systems, underlining a solution that brings less manual input, supports a more realistic and precise version, and makes greater advantages of the use of less data. The exciting opportunities coming from deep learning, object detection, and image processing promise this kind of improvement in the efficiency and quality of visualizations in 3D.

In due course, the focus should be on taking forward the research done from this literature survey and scrutinizing the current issues in those methodologies that are being considered problematic and in need of improvement. If advanced machine learning algorithms and automation methodologies were included, these systems could become more robust in direct production of high-quality interactive 3D environments from low-quality 2D plans with minimal user interventions. However, the scope of applications in architecture, real estate, and virtual reality is of great magnitude, promising a more streamlined design process along with better user experiences as these technologies continue to advance. Further research would continue to advance architectural visualization and move toward allowing designers and architects to use smarter and more efficient tools in the years ahead.

## Acknowledgment

The authors wish to convey their heartfelt appreciation to the faculty and staff of the Computer Science Engineering Department at the College of Engineering Chengannur for their invaluable support and provision of necessary resources for this research. Gratitude is also extended to our colleagues and mentors for their insightful feedback and constructive guidance throughout the creation of this paper. Lastly, we acknowledge the efforts of researchers whose work has significantly influenced advancements in interactive 3D visualization methodologies.

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