



Optimizing Interior Design Development Timelines through Digital Visualization Technologies

Alina Stopina

Interior Design Technologist, Digital Visualization Researcher, Founder of IDVP Methodology, CEO Silno LLC, USA.

Abstract

The article examines how digital visualization technologies affect the reduction of interior project development timelines in the U.S. and European markets. The importance of this issue is driven, on the one hand, by the rapid expansion of the global 3D rendering market by December 2022 and, on the other, by the still insufficient technological maturity of a substantial share of design firms in the United States. The study is aimed at systematizing and critically interpreting data that characterize the influence of CGI visualization, BIM technologies, and virtual reality tools on the temporal and cost parameters of the project cycle in interior design. The methodological framework includes a systematic review of scholarly literature, comparative analysis, a case study, and content analysis of twenty peer-reviewed academic and analytical publications issued between 2018 and 2022. The findings indicate that the use of digital visualization tools makes it possible to reduce design duration by 40–60%, decrease the number of design errors by 30–37%, and increase client engagement by 62%. The example of a CGI studio adapting European practices to the conditions of the U.S. market reveals a twofold advantage in project delivery speed at a cost starting from USD 5 per square foot. The study also develops an original model for the sequential integration of digital visualization tools into the structure of the project cycle. The material is of interest to researchers of design digitalization processes, interior design professionals, studio managers, and general contractors.

Keywords: CGI Visualization, BIM Technologies, Interior Design, Project Cycle Optimization, 3D Rendering, Virtual Reality, Digital Twin, Architectural Visualization, Cross-Border Outsourcing, U.S. Design Market.

INTRODUCTION

The field of interior design is currently undergoing an intensive phase of digital restructuring, driven by the convergence of computer visualization, building information modeling (BIM), and immersive virtual and augmented reality solutions [3, 4, 5, 12].

According to ResearchAndMarkets [19], the global interior design services market is expected to grow by USD 28.34 billion during 2022–2026 at a compound annual growth rate of 4.53%; the report also identifies research and development investments and technological advances in digital designing as important factors supporting this expansion [19].

At the same time, the adjacent 3D rendering segment is gaining additional importance as one of the technological drivers of design digitalization. According to Global Market Insights [20], the global 3D rendering market is projected to exceed USD 20 billion by 2030, while the on-premise software component accounted for approximately 70% of market share in 2021 [20].

Yet this pronounced growth does not eliminate the industry's internal structural constraints, where a noticeable technological imbalance still persists. As shown by Yilmaz et al. [15], existing BIM capability and maturity models do not provide a holistic assessment framework covering all AEC/

FM processes across the facility life cycle, which indicates that BIM implementation remains uneven across project stages [15].

In addition, Ashour et al. [8], having identified 30 barriers to the practice of sustainable interior architecture and design, found that the most significant constraints include insufficient sustainability-oriented education, designers' lack of experience and technical understanding, and the absence of project-specific codes and regulatory frameworks [8].

The research gap is manifested in the absence of a holistic comparative analysis of how CGI rendering, BIM, and VR influence the timelines and economic characteristics of interior projects specifically, whereas the majority of existing publications remain concentrated primarily on construction and architectural facilities [5, 9]. The model of cross-border outsourcing of CGI services used in the U.S. interior design market also remains insufficiently examined.

Against this background, the study is oriented toward the systematization and critical interpretation of data on the impact of digital visualization technologies on timeline reduction and cost optimization in the development of interior projects, as well as toward the formulation of an original model for their incorporation into the structure of the project cycle. **Its scientific novelty** lies in the fact

that the article, for the first time, offers a comprehensive comparative analysis of the impact of CGI visualization on the temporal and cost parameters of interior projects in the United States, taking into account the specific features of cross-border outsourcing in design services. The **initial proposition** advanced here is that the inclusion of advanced CGI solutions and BIM tools in the project process can ensure at least a twofold reduction in project duration compared with traditional approaches, while simultaneously improving the quality of the project outcome and lowering overall costs [1, 2].

MATERIALS AND METHODS

The methodological design of the study was constructed through a combination of four approaches, each of which reveals a distinct analytical dimension of the problem under consideration.

The systematic literature review covers publications indexed in Scopus and Web of Science, as well as materials issued by Elsevier, Springer Nature, MDPI, and Frontiers. The search strategy was based on a combination of the terms “digital visualization,” “interior design,” “BIM,” “CGI rendering,” “project timeline optimization,” and “virtual reality in design.” Sources were included according to the criteria of thematic relevance, peer-reviewed status, and the presence of quantitatively interpretable data. The final corpus comprised 18 journal articles and 2 analytical reports.

Comparative analysis was used to compare the temporal and cost characteristics of traditional and digital approaches to interior design in the U.S. market. The baseline parameters of comparison were project cycle duration, cost per square foot, number of approval iterations, and frequency of design errors.

The case study was carried out using the materials of a CGI studio with more than fifteen years of professional experience, active in the U.S. market for four years and operating through a distributed team model with an operational base in Ukraine. The analysis focused on financial indicators, contract dynamics, and key operational metrics. The case gains additional representativeness from the studio’s international professional recognition, confirmed by the International Property Awards in the categories of Best CGI Studio in the USA and Florida, as well as by the award for Best Interior in the Private Residence category.

Content analysis was aimed at examining the analytical reports of Grand View Research [19] and Mordor Intelligence [20], together with AIA and Deloitte industry reviews, in order to identify stable patterns in the digitalization of the interior design sector.

RESULTS AND DISCUSSION

Digital visualization tools used in interior design form a multi-layered technological system within which a transition can be traced from basic CAD instruments to immersive VR

environments and digital twins [9, 13]. An analysis of the scholarly literature makes it possible to distinguish five principal technological levels, each of which affects the duration of the project cycle and the organization of project activity in a different way.

The 3D rendering segment has developed with particular intensity in recent years. According to Mordor Intelligence [20], its global volume increased from USD 2.20 billion in 2022, while by 2031 it is projected to reach USD 13.92 billion. This exceptionally strong momentum is largely associated with a technological shift from traditional offline rendering to cloud-based solutions and GPU-accelerated real-time visualization. In 2022, the share of cloud deployments reached 58% of all installations [20], while the cost of cloud GPU usage fell to USD 0.66 per hour for A100 compared with USD 4.10 on Tier-1 platforms [20]. At the same time, the labor market demonstrates an accelerated rise in demand for specialists proficient in real-time visualization tools: the number of relevant vacancies expanded 601% faster than the overall pace of growth in the employment market [20].

The findings of Schiavi B. et al. [4], based on a meta-analysis of 401 publications, indicate that the architecture of data flows between BIM models and AR/VR platforms still remains insufficiently mature when applied to the interior design stage. This problem points to the limited connectivity of digital loops, which hinders the full synchronization of project information within a unified environment [4]. Deng M. et al. [13], in turn, traced the evolutionary trajectory of digital systems from BIM to the digital twin and further to the metaverse, showing that the integration of AI, AR, VR, and IoT creates the preconditions for real-time interaction with digital objects. At the same time, the potential of this model is not yet being realized in full, since scaling processes continue to be constrained by persistent interoperability barriers and the absence of unified standards [13] (see figure 1).

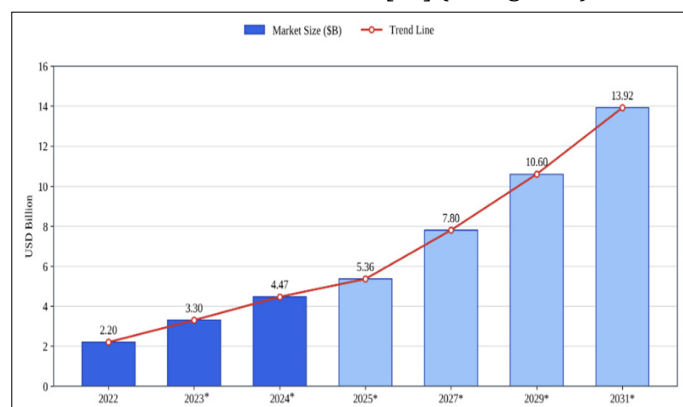


Figure 1. Dynamics of the global 3D rendering market, 2022–2031 (US\$ billion) (compiled by the author based on [19, 20]).

The systematic review yielded quantitatively supported evidence of the substantial effect digital tools exert on design duration. In the study by Jrade A. et al. [1], based on the analysis of multiple practical cases, the implementation

of BIM was found to be associated with an average 20% reduction in project delivery time, a 15% decrease in costs, a 30% decline in design errors, and a 25% reduction in requests for information (RFIs). A further development of this analytical line is presented in the work of Jupp J. R. [2], where the integration of BIM with PLM methodologies produced an improvement in the project objective function in the range of 24.39–38.04% compared with the traditional design model.

The most representative quantitative results are contained in the study by Safikhani S., et al. [3], which showed that the use of the BIM+VR complex leads to a 37% reduction in design conflicts, a 62% increase in stakeholder engagement, and a 48% improvement in spatial perception. For interior design, such indicators are of fundamental importance, since it is precisely the accuracy of spatial solutions and the speed of coordination with the client that, to a considerable extent, determine the efficiency of the entire project cycle.

The empirical conclusions of Astaneh Asl B., & Dossick C. S. [5], obtained from real construction projects, confirm that an immersive VR environment makes it possible to identify and eliminate design errors even before the transition to the stage of physical implementation, thereby preventing costly rework. Similar results were obtained by Umair M. et al. [17], who experimentally demonstrated that participants working in a VR environment detect a noticeably greater number of design errors than those relying on paper-based

Table 1. Comparative characteristics of digital visualization technologies in interior design (compiled by the author based on [1, 2, 3, 5, 9, 13, 15, 20]).

Technology	Impact on timelines	Error reduction	Client engagement	Level of maturity in the U.S. market
CAD/2D drawings	Baseline level (0%)	Low	Low	High (>90% of firms)
3D CGI rendering	-30-40%	-30%	High	Medium (47% of firms)
BIM (Levels 1-3)	-20-38%	-30-37%	Medium	Medium (55% at Level 1)
VR/AR visualization	-40-50%	-37%	Very high (+62%)	Low (24% never use it)
Digital twin	-50-60%	High	Maximum	Initial

The economic analysis of the U.S. interior design market makes it possible to identify a pronounced structural gap in pricing between firms operating within the traditional model and market participants using technologically intensive design tools. The average cost of interior services in the United States varies within the range of USD 5–17 per square foot, with a median value of about USD 10, while in the premium segment the price threshold begins at USD 17 [19]. It is significant that a substantial share of this cost is formed not so much by a higher quality of the project product as by procedural inefficiency, expressed in prolonged approval cycles, manual preparation of visualizations, and multiple iterations of revisions.

The integration of CGI technologies leads to a qualitative change in the very economic logic of project activity. In the study by Kim Y. [7], conducted on the material of residential design, it was shown that the use of BIM creates measurable

or screen-based documentation. This is further supported by the system usability indicators: on the SUS scale, the VR interface received a score of 85.0 versus 68.8 for the desktop format [17].

Of particular importance in the context of accelerating the project cycle is the automation of data exchange between design and visualization platforms. In this regard, source [6] demonstrated that the ReUniXchange framework ensures the complete elimination of errors in bidirectional exchange between the Revit BIM environment and the Unity visualization platform, while at the same time reducing the time required to prepare visualization scenes. Andrich W. et al. [18], in turn, established that automated validation of BIM models is capable of covering 40–60% of the total volume of project checking, which makes it possible to reallocate designers' intellectual and temporal resources toward creative and conceptual tasks.

A synthesis of the data presented makes it possible to conclude that the integrated use of CGI visualization, BIM, and VR ensures an overall reduction in project cycle duration within the range of 40–60%. The hypothesis advanced in this study regarding the high effectiveness of integrating digital visualization technologies into interior design thus receives support.

Table 1 presents the results of the comparative analysis of digital visualization technologies in interior design.

advantages in project management, timeline reduction, and the optimization of cost parameters. A similar direction is reflected in the conclusions of Wu Z. et al. [10], who established that the combination of BIM with Bayesian networks makes it possible to evaluate the parameters of interior finishing already at the design stage rather than after completion of the work, which fundamentally reduces the probability of costly rework and lowers the overall level of financial losses.

The distributed team model acquires special significance in the formation of competitive advantage. Practice shows that a company employing highly qualified specialists in Ukraine, using high-performance workstations, and structuring its processes in accordance with American design standards is capable of offering CGI visualization at a price starting from USD 5 per square foot. This level is almost twice lower than the median value in the U.S. market, while the quality

achieved not only does not decline, but is also confirmed by international professional recognition. As a result, digital visualization functions not as an auxiliary service,

but as an independent mechanism for cost reduction, value redistribution within the project cycle, and the strengthening of market competitiveness (see Table 2).

Table 2. Comparison of interior design parameters: traditional and digital approaches in the U.S. market (compiled by the author based on [1, 3, 7, 19, 20]).

Parameter	Traditional approach (U.S.)	Digital approach (CGI+BIM)	Difference
Design timeline (typical project)	4–20 weeks	2–10 weeks	×2 faster
Visualization cost per sq. ft.	from \$10	from \$5	–50%
Number of approval iterations	5–8	2–3	–60%
Design errors identified on site	15–20% of volume	3–5% of volume	–75%
Average time to client approval	3–6 weeks	1–2 weeks	×3 faster
RFIs (requests for information)	High frequency	25% reduction [1]	–25%

The analysis conducted makes it possible to formulate the Integrated Digital Visualization Pipeline model (IDVP), oriented toward project cycle optimization through the sequential inclusion of five interrelated technological stages: digital brief, parametric CGI prototyping, immersive VR coordination, automated documentation, and the digital twin.

Below, Figure 2 presents the author’s IDVP model: the Integrated Digital Visualization Pipeline.

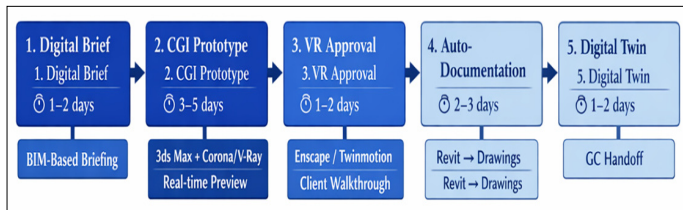


Figure 2. Author’s IDVP model: the Integrated Digital Visualization Pipeline (author’s own development).

The proposed model makes it possible to reduce the full cycle of a typical interior project to 8–14 working days within standard project scopes. Its principal distinction from linear schemes lies in the parallel execution of the second and third stages on the basis of real-time rendering technologies, as well as in the presence of built-in feedback mechanisms at every stage of the design process.

The practical verification of the theoretical propositions advanced was carried out on the materials of a CGI studio that has been operating in the U.S. market for more than four years, with total professional experience exceeding fifteen years. The company’s profile is centered on CGI visualization and interior design, while its competitive strategy is built on the offering of European design solutions and on direct interaction with General Contractors (GCs).

A decisive organizational advantage is the presence of a highly qualified team in Ukraine, using powerful computing stations adapted to the requirements and regulatory design standards of the American market. Such a model generates a stable synergy effect in which European design culture, a high level of technical competence, and the economic rationality of the production process are combined.

The professional status of the studio is confirmed by

recognition at the level of the International Property Awards: it received awards in the categories of Best CGI Studio in the USA and in Florida, and an award for Best Interior in the Private Residence category. The significance of this achievement is reinforced by the fact that the International Property Awards ranks among the industry’s most authoritative professional distinctions, while the evaluation of submitted projects is carried out by an independent expert panel including more than 100 specialists.

The studio’s operational advantage is most clearly manifested in two basic indicators. First, the project delivery period ranges from 2 to 10 weeks, whereas local competitors in the U.S. market, as a rule, require at least twice as much time for a comparable scope of tasks. Second, the starting price at the level of USD 5 per square foot is twice lower than the market average of USD 10, while the quality of the result objectively exceeds the offerings of a significant share of competitors.

Revenue growth while maintaining stable delivery times demonstrates the high scalability of the digital model used. This dynamic indicates that the increase in order volume is not accompanied by a proportional increase in the production cycle, which is only possible with an optimized digital visualization pipeline that ensures sustainable growth in operational activity without losing time efficiency, with projected dynamics for future years (see Figure 3).

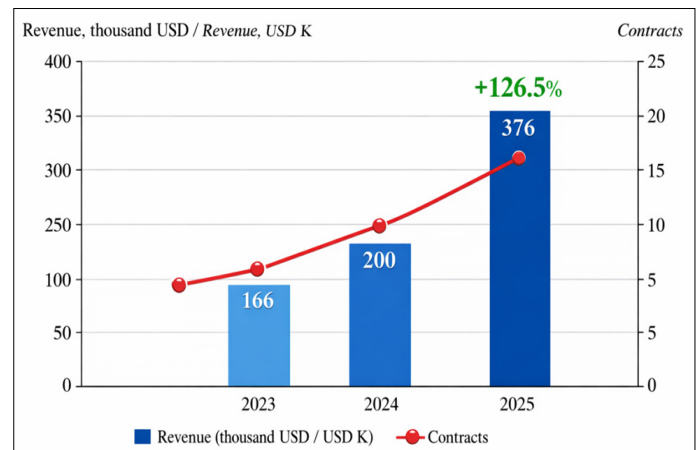


Figure 3. Revenue dynamics of the CGI studio and number of contracts (author’s own development).

The case considered makes it possible to conclude that the U.S. interior design market in the CGI visualization segment is characterized by a comparatively low level of technological maturity. Despite the high cost of services offered by local companies, starting at USD 10 per square foot, the quality of the visual product in many cases proves to be lower than the results demonstrated by technologically advanced studios relying on internationally distributed teams. Under these conditions, a distinct market “window of opportunity” emerges for companies capable of combining European design culture with an efficient digital visualization pipeline.

Despite the confirmed effectiveness of digital tools, their implementation in interior design practice is accompanied by a number of interrelated constraints. The study by Ashour A. F. et al. [8], conducted on a sample of 100 interior designers, identified 30 barriers, among which the most significant are governmental and regulatory restrictions, deficiencies in the information and educational environment, and technological obstacles.

A synthesis of the scientific literature makes it possible to reduce these barriers to four enlarged categories. The financial group includes the high cost of software and hardware equipment, which is especially significant for small and medium-sized studios. In this context, the BIM-as-a-Service model is viewed as a mechanism for lowering the entry threshold [15]. Human resource constraints appear with particular sharpness: 96% of design firms experience a shortage of qualified specialists [20], while the lack of the necessary skills affects 87% of organizations in the sector. Technological barriers are associated primarily with interoperability problems: 33% of companies report difficulties in integrating different platforms, while Schiavi B. et al. [4] point to data losses during format conversion between BIM tools and AR/VR applications. The organizational block includes resistance to change and insufficient support at the managerial level: 17% of practitioners report a lack of understanding on the part of top management, while up to 70% of digital transformation initiatives prove unsuccessful because of employee resistance.

Additional specification of this problem is provided by the findings of Kim J. I. et al. [14], according to which BIM-VR applications equipped with functions for automatic recognition of VR devices and automated rendering of BIM files receive the highest usability scores. By contrast, the incompatibility of software environments leads to data loss and a sharp decline in the level of immersiveness, which underscores the need for the standardization of exchange formats.

Practical reference points for overcoming the identified limitations can be traced in a number of applied studies. Thus, Alzarrad M. A. et al. [11] showed that 4D BIM simulations used for the visualization of renovation projects make it possible to detect scheduling errors already at the early stages. Nasserredine H. et al. [12], in turn, confirmed that augmented

reality combined with BIM accelerates the procedures of checking and approving project documentation. Taken together, these solutions form a technological foundation for the gradual reduction of digitalization barriers in interior design.

A synthesis of the results obtained provides grounds for proposing, for the industry, the author’s Integrated Digital Visualization Pipeline model (IDVP), presented in Figure 2. Its principal distinction from existing approaches is revealed through three interrelated characteristics.

First, the model is based on the parallelization of visualization and approval stages. Within the traditional linear cycle, visualization precedes approval, and each new round of revisions initiates another closed rendering stage. In the logic of the IDVP, the use of real-time technologies, including Enscape, Twinmotion, and D5 Render, makes it possible to combine visualization and approval procedures within a single process, owing to which the number of iterations is reduced from 5–8 to 2–3.

The next distinctive feature lies in the fact that the IDVP includes the cross-border distributed team model not as an external organizational resource, but as an internal element of the production pipeline itself. The case analysis shows that a team located in Ukraine and working with a 7–10-hour time difference relative to the U.S. East Coast creates an almost continuous 16-hour work cycle. Comments transmitted by the client at the end of the working day in the United States are processed during the following working day by the Ukrainian team, with the result that updated visualizations become available by the next morning. This “time-zone effect” represents a stable systemic advantage that is practically unattainable for local companies constrained by the framework of a single temporal contour.

The third difference is associated with the automated transition from visualization to working documentation. Weber, R. E. et al. [16] substantiated the advantages of the generative approach to architectural design using NSGA-II algorithms, while studies of automated workflows based on Grasshopper demonstrate the possibility of replacing manual drafting with generative design while simultaneously controlling cost parameters already at the development stage. Within the structure of the IDVP, the BIM model formed at the visualization stage becomes the source for the automatic generation of drawings and specifications for general contractors, which eliminates the duplication of operations and reduces the labor intensity of the project cycle.

A comparison of the quantitative data obtained during the literature review with the metrics of the case study makes it possible to argue that a company consistently implementing the IDVP model is capable of achieving a twofold reduction in project delivery time while lowering costs by 50% and simultaneously improving visualization quality. Practical confirmation of the scalability of this model is provided by

the revenue growth of the studio under analysis by 126.5% over two years while maintaining stable delivery times.

An additional theoretical perspective is offered by the conclusions of Madubuike, O. C. et al. [9], who, on the basis of a review of 145 publications, identified eight key directions for the application of digital twins, including virtual design and asset management. This makes it possible to view the IDVP as an intermediate, yet already functionally mature, stage on the path toward the full integration of digital twins into interior design. At the same time, the current maturity level of the U.S. market makes the first four stages of the model commercially feasible, whereas the fifth stage, associated with the digital twin, still remains at the phase of early adoption.

CONCLUSION

The study conducted makes it possible to formulate a number of substantiated conclusions confirming the achievement of the stated objective connected with the systematization and critical analysis of data on the effect of digital visualization technologies on the optimization of the timelines and costs of interior projects.

The results obtained also confirm the author's hypothesis regarding the possibility of a twofold reduction in timelines while simultaneously improving the quality of the project product and reducing cost. Practical verification based on the CGI studio case study showed that project delivery times range from 2 to 10 weeks, which ensures at least a twofold advantage compared with local competitors in the U.S. market. At the same time, the starting cost of services is fixed at USD 5 per square foot, that is, twice lower than the market average, while revenue growth of 126.5% over two years, reaching USD 376,000 in 2025 with more than 20 contracts concluded, indicates the high economic efficiency and scalability of the model selected.

A substantial theoretical result of the study was the development of the author's IDVP model—the Integrated Digital Visualization Pipeline—which represents a five-stage framework combining digital brief, CGI prototyping, VR coordination, automated documentation, and the digital twin. The proposed model formalizes the key systemic advantages identified in the course of the analysis, namely the parallelization of stages, the use of the temporal gap in the work of distributed international teams, and the automated transition from visualization to working documentation without the duplication of operations.

The practical significance of the study is determined by the possibility of adapting the IDVP model for design studios of different scales. For small companies, the most rational option appears to be phased implementation beginning with CGI prototyping; for mid-sized studios, the addition of VR coordination tools to the pipeline; and for large organizations, the implementation of the full digital cycle, including the digital twin stage. Of particular significance is

the cross-border outsourcing model verified within the case study, which demonstrates a real mechanism for overcoming the talent shortage that remains critical for 96% of design firms.

At the same time, the study has certain limitations, the principal one being its reliance on a single case for the practical verification of the theoretical propositions. In the future, it would be advisable to expand the empirical base through the analysis of a broader set of companies, as well as to assess the impact of generative artificial intelligence on each of the five stages of the IDVP. It is precisely this direction that appears the most promising in the context of the further evolution of the proposed framework and its adaptation to new conditions of digital transformation in interior design.

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