Pre-Design Visualization: The Prospect of Real-Time Evaluative Methods in the Design Process

FANG XU
South Dakota State University

Keywords: visualization, parametric design, simulation, design evaluation, participatory design

The rise of computer-generated imagery has significantly changed the landscape of architectural visualization. However, the digital turn brings little shift to the role of visualization in the architectural design process. Post-design visualization remains a dominant paradigm in practice. This paper advocates the development and adoption of pre-design visualization methods. Pre-design visualization transforms architectural visualization from a discrete and post-design task into a general action ubiquitous in all design stages and preceding formal decisions. Pre-design visualization affords a real-time visualized design environment that generates and fuses massive visual data of essential design information. Such a design environment considerably augments the dialogue between the architect and the formal scheme under development, facilitating informed decision-making in a cyclical design process.

The paper demonstrates the strengths of pre-design visualization through three real-time design games that the author developed. These games allow the architect to initiate, modify, and evaluate design schemes in an interactive 3D environment that features visualized physical contexts, adaptable weather and daylight systems, human performance simulation, visualized design parameters and statistics, and design evaluation tools. The following discussion illuminates the practical values of pre-design visualization for architects and different actors and stakeholders in multiple design scenarios. The paper is concluded by a discussion of immediate research directions for pre-design visualization: interoperability of pre-design visualization tools with mainstream design programs in a data-driven, computational design workflow, simulation of complex person-environment interactions, and flexibility in media deployment.

INTRODUCTION

Architectural visualization generally refers to the technique or action that produces expressive visual imagery for design communication. As part of the overarching image-making efforts that remain central in architectural design, architectural visualization has long been a promotional means to advertise design ideas (Porter 2000; Yee 2007). Typically involving perspective views, architectural visualization is expected to bring "the viewer into contact with the sensory qualities of designed form and space, communicating a "you are there" experience (Porter 2000, 52). Such an understanding implies that architectural visualization is a post-design action after the design proposal reaches a certain level of maturity. The predominant design process endorsed by practicing architects, architectural educators, and students has spawned and reinforced the concept of post-design visualization.

Due to the continued democratization of information technology since the late 20th century, digital automation methods known as Computer-Aided Design (CAD) have elevated architects' productivity in many design activities (Hauschild 2011; Martens and Brown 2005). Architectural visualization has also undergone a major transition as 3D digital renderings gradually supplanting manual illustrations (Yildirim and Yavuz 2012; Koutamanis 2000). Many advanced 3D rendering technologies gradually became available and affordable to architects. These technologies have propelled architectural renderings to continuously evolve, achieving detail and exactness in expression of spatial perception.

However, the digital turn in architectural visualization brings little change to the role of visualization in architectural design. Post-design visualization, as a dominant paradigm holds sway in the digital age. Painting brushes giving way to mouse cursors does not stimulate architects to reconceptualize visualization. As far as the design process is concerned, photorealistic renderings are not significantly distinct from watercolor illustrations since architects see both as post-design visualization products. Other professionals participating in the production of the built environment, likewise, are not aware of any salient workflow revision brought by the digitalization of architectural visualization.

The most recent advancement of 3D graphics technologies seems to illuminate an outlook where architectural visualization will attain a pivotal position in design. Instead of being a sporadic, post-design task, architectural visualization can be an omnipresent, pre-design action that occurs in all design stages and heralds formal design decisions (Figure1). With pre-design visualization, architects can conceive, prototype, and iterate formal proposals in an integrated 3D design environment that

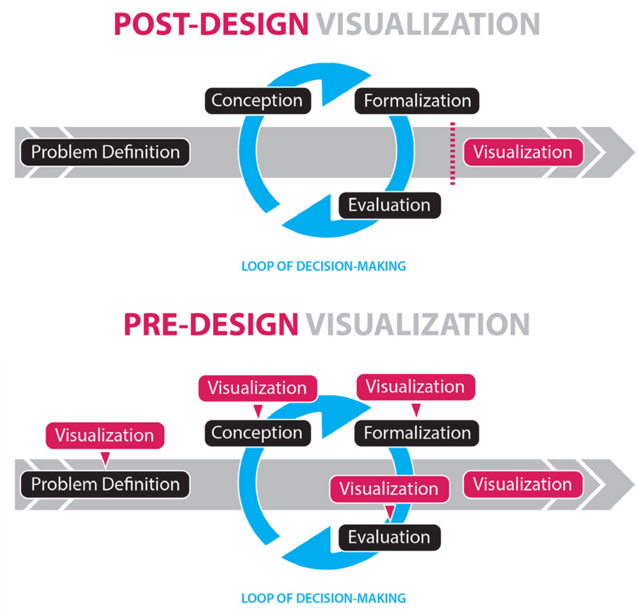

Figure 1. Comparison of Post-Design and Pre-Design Visualization. Source: Author.

fuses parametric modeling and visualization in real-time. Such a 3D design environment gives intuitive feedback for reflexive evaluation in a cyclical design process and can serve as a communication nexus for the generation, interpretation, and distribution of ad-hoc knowledge among all actors involved in the design and building process, helping bridge the communicative cleavage between architects and non-designers. Clients and public stakeholders can be more participatory in the design process, which is particularly valuable for community-based projects.

TECHNOLOGICAL CONTEXT

Since the advent of 3D graphics, the technological resources suitable for application in architecture have expanded thanks to the remarkable growth of video game industry[1]. In the past decade, major 3D technological milestones, such as Global Illumination (GI) and Physically Based Rendering (PBR) have redefined architectural visualization with substantially improved lighting and materiality fidelity. Currently, the industrial context is conducive for applying pre-design visualization in architecture because the technologies of real-time rendering and script-based procedural modeling that offer essential support.

Producing images in real-time, real-time computer graphics have accompanied the birth and development of video games. But it is not until the very recent when the quality of real-time 3D imagery generated at a rate of over 30 frames per second draws near to that of static renderings a single frame of which typically takes minutes or hours to complete (Walfisz, Zackariasson, and Wilson 2006). The tremendous performance gain without markedly compromising quality means architects can efficiently create animated imagery to reveal behavioral and visual implications of the designed environment. Also, real-time rendering makes high-resolution rendering much more cost-effective, which is necessary for constructing immersive visual experiences through panoramic rendering or VR (Virtual Reality).[2] Today, architects can execute real-time rendering in some visualization programs (e.g., Enscape and Twinmotion). For complex rendering scenes, real-time solutions still cannot emulate conventional static rendering (e.g., V-Ray or Maxwell) in quality. But their increasing popularity among practicing architects showcase the appeal of real-time visualization.[3]

Script-based procedural modeling or parametric modeling refers to the technology to build varying 3D models and materials by adapting parameters in a procedural script. Procedural modeling provides adaptivity in the production of 3D assets to facilitate the construction of large game levels.[4] Some latest architectural rendering programs have introduced procedural assets to enhance usability. For example, Lumion boasts of an interactive material system for users to create special material effects (e.g., weathered, wet, or vine-covered) by adjusting a few parameters, granting architects with greater direct controls over components in a visualization project. The parametric design movement in architecture echoes the growing influence of procedural modeling.

Real-time rendering and script-based procedural modeling have laid the foundation for pre-design visualization. The former makes possible instantaneous visualization of design schemes, and the latter means architects can efficiently create, modify, and iterate formal prototypes in response to the visual feedback from real-time rendered imagery. Despite the transiting 3D visualization landscape, corporations providing CAD software services today show a clear path dependence on post-design visualization. Modern CAD programs unanimously embrace a conspicuous distinction between the functions for creating and modifies geometries and those for producing rendered perspectives: visualization software programs either exist as plugins of mainstream modeling programs (e.g., Revit, Rhino, or SketchUp), or as standalone applications that rely on modeling programs for 3D geometrical data. Neither approach accommodates a close-knit association of modeling and visualization. Such a situation hinders practicing architects from understanding pre-design visualization and recognizing its exceptional merits.

METHODS OF PRE-DESIGN VISUALIZATION

While there is no commercial pre-design visualization software available for architects, it is possible to improvise an equivalent computational procedure. For educational and research purposes, the author has built several real-time “design games” that demonstrate the basic functionality and practicability of pre-design visualization. All these games were developed in Unreal Engine, a versatile, industrial standard game engine known for its real-time visualization competence and Blueprint,

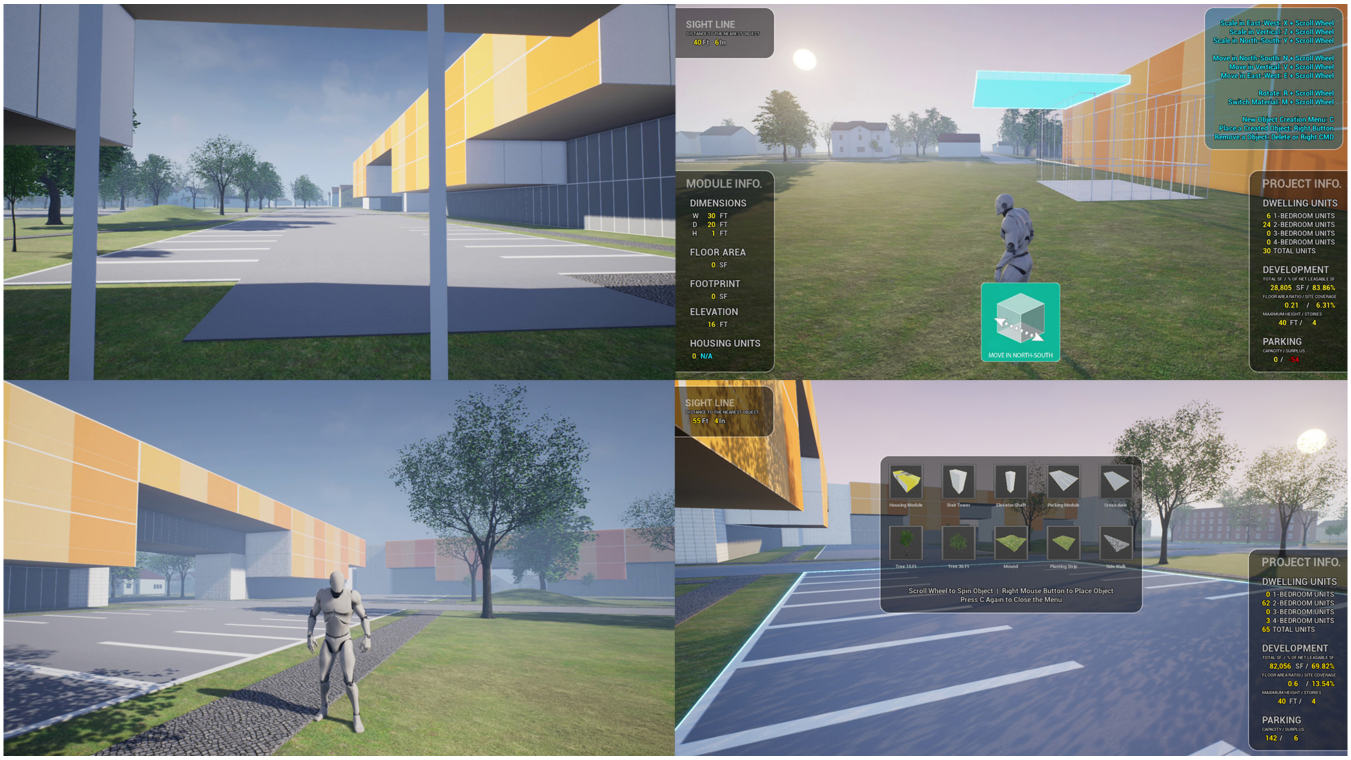

Figure 2. Screenshots of Building Massing Explorer. Source: Author.

a built-in visual scripting system akin to that of Grasshopper for Rhino or Dynamo for Revit. As interactive digital media that manifest real-time visualization in the design process, these games appear as a critical node in a data-driven parametric design workflow. The present study spotlights three design games: Building Massing Explorer, Generative Façade, and Parametric Wall Observer.

Building Massing Explorer

Building Massing Explorer is a design game for students or practicing architects to explore massing concepts for a multi-family housing development project. The game features a real-time visualized urban context, playable human and vehicle characters as avatars for simulating human vision and behaviors, an inventory of buildable procedural objects, and an interactive User Interface (UI) system for customizing settings and displaying design data (Figure 2). Once entering the game, the designer can control the human or vehicle character to roam freely in the real-time rendered 3D urban environment to approach, traverse, circumvent, or depart from the building site along different routes and at varied speeds, simulating multiple static or dynamic visual experiences of the existing environmental elements on and around the site. The designer can build procedural modules of apartment units, parking spaces and aisles, and landscape components, including lawn strips, sidewalks, mounds, and paved surfaces.[5] As the procedural modular objects begin to accumulate in the scene, the game displays real-time design data such as apartment units, square footage, floor-area-ratio, parking units, etc. (Figure 2). These data, along with the instantaneous visualization of the building mass in the context provide simulation-based evidence for design evaluation. Interacting with the game's immersive 3D design environment that gives visualized evaluative information in real-time, the designer continually evaluates, modifies, and iterates the shifting massing scheme she is developing.

The game turned out to be particularly useful for architectural students who lack the experience to foresee the conflicting demands of design goals and the complex performance implications of building massing. Through the game, students intuitively understood the probable real-world outcomes of their abstract massing concepts, hence learning to make justifiable, professional design decisions (Figure 3).

Generative Façade

Generative Façade is a prototypical design game for post-parametric, generative façade design of a boutique hotel at a real urban infill site in downtown Watertown, SD. It empowers architects to explore and present design solutions adapted for design scenarios with changing goals, priorities, and restrictions. The game visualizes the 8-block downtown area and incorporates a playable human character featuring the same visual and behavioral simulation capabilities as that of the Building Massing Explorer. In the game, the designer can operate the human character to observe, modify, and evaluate a procedural hotel building façade defined by some 18 underlying parameters. Some of the parameters are numeric (e.g., width and height of individual guest rooms, depth of windowsills, or

Figure 3. Students used Building Massing Explorer in studio. Source: Author.

ratio of different window shading colors). Others are categorical variables assigned with nominal quantitative values (e.g., alternate design approaches to position window shadings with 0 for orderly arrangement and 1 for randomization).

Generative Façade

Generative Façade is a prototypical design game for post-parametric, generative façade design of a boutique hotel at a real urban infill site in downtown Watertown, SD. It empowers architects to explore and present design solutions adapted for design scenarios with changing goals, priorities, and restrictions. The game visualizes the 8-block downtown area and incorporates a playable human character featuring the same visual and behavioral simulation capabilities as that of the Building Massing Explorer. In the game, the designer can operate the human character to observe, modify, and evaluate a procedural hotel building façade defined by some 18 underlying parameters. Some of the parameters are numeric (e.g., width and height of individual guest rooms, depth of windowsills, or ratio of different window shading colors). Others are categorical variables assigned with nominal quantitative values (e.g., alternate design approaches to position window shadings with 0 for orderly arrangement and 1 for randomization).

The game provides an intuitive on-screen console menu for the user to adjust design parameters, change daylighting and weather conditions, or select modes of automatic design generation strategies that reflect different design considerations (Figure 4). To explore and compare design schemes, the user can manually modify individual parameters or choose to automatically generate some iterations based on combinations of randomly set parameters. The user can freeze the values for certain parameters, then launch the auto-generation process that randomizes the remaining parameters. Most parameter values are set through manual input or auto-generation, while some parameters may obtain dynamic values according to a certain real-time situation of the human character during the gameplay.[6]

The author introduced Generative Façade to a graduate design studio and inspired students to utilize it as a template to build their façade design games. Capitalizing on these games' real-time visual simulation and parametric design generation capabilities, students systematically studied the boutique hotel façade design and proposed sets of solutions optimized for different initial design conditions. They presented their redeveloped versions of Generative Façade to residents of Watertown in a community participatory design event. Inviting laypersons to play the games, students observed and learned about Watertown locals' attitudes about a proposed downtown architectural guideline that regulates material and proportional designs in new constructions to ensure formal conformity in the downtown area.

Parametric Wall Observer

Comparable to Generative Façade, Parametric Wall Observer synthesizes parametric design with real-time visualization. Yet Parametric Wall Observer focuses on the visual perception simulation for assisting design studies at the level of architectural details. The game visualizes a segment of a brick wall, the form of which is characterized by 11 parameters. These parameters control the overall dimensions of the wall, form, and spacing of individual bricks, bricklaying styles, and other design traits. The playable human character has three camera views for visual stimulation: first-person, third-person, and distance. The first-person view is from a camera with a 90-degree field of view (FOV) located exactly at the character's eyes. Third-person and distance views have the camera located at 400 centimeters (13.1 feet) and 6000 centimeters (196.9 feet) behind the eyes, respectively. While playing the game, the designer can conveniently simulate visual perceptual qualities of the wall by controlling the player character to approach or

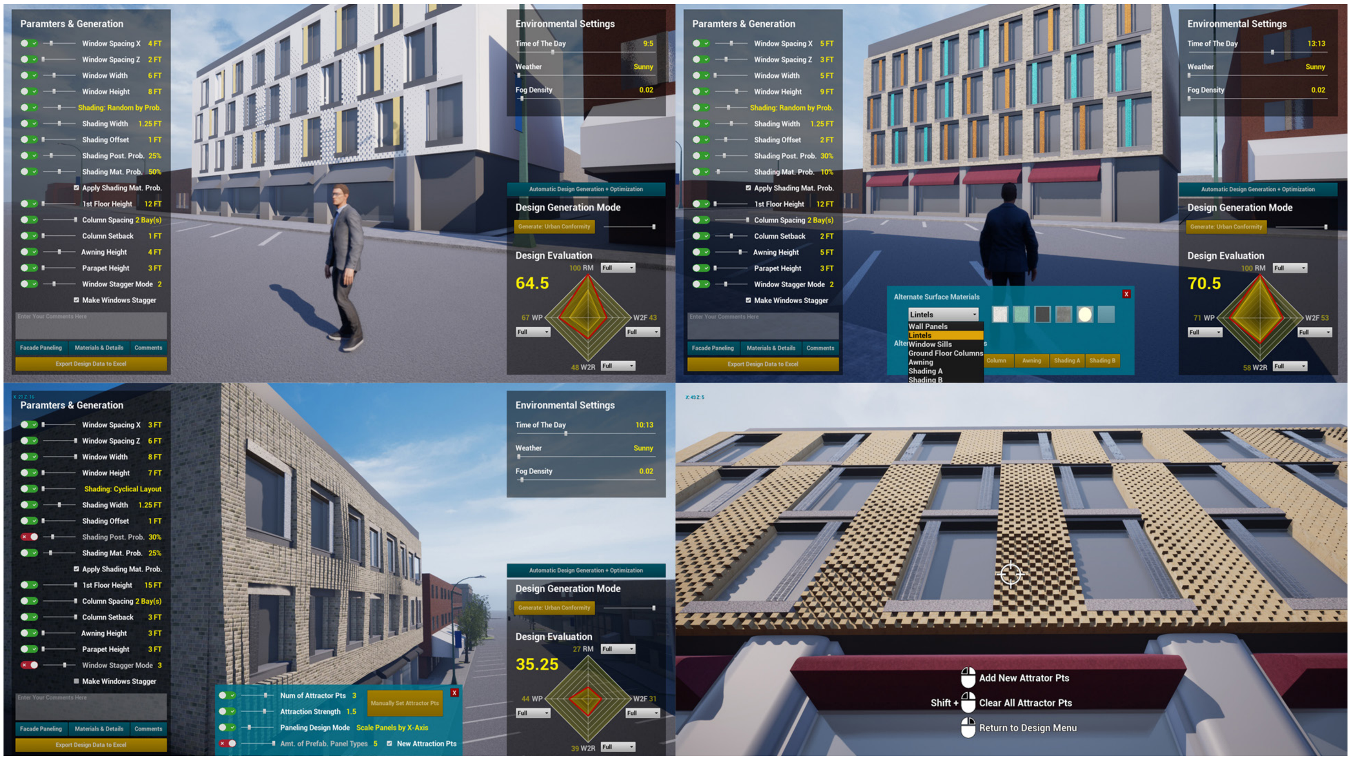

Figure 4. Screenshots of Generative Façade. Source: Author.

depart from the parametric wall and by switching between different camera views. To modify the wall design, one can turn on a game pause menu to browse and select parameters, and then adjust selected parameters using the mouse scroll wheel back in the game (Figure 5).

Architects can utilize Parametric Wall Observer to perform a simulation-based evaluation of parametric wall designs. When modifying detailed design attributes including reveals, brick joints, and brick offsets, the designer can obtain real-time visualization outcomes about how wall details of alternate designs appear to human eyes in varying distances.[7] The game pause menu also includes options to change miscellaneous environmental settings, for example, date and time of the day, fog density, and season, further expanding the game's visual simulation capacity. For beginner designers, especially those lacking perceptual knowledge about visual implications of building details, Parametric Wall Observer helps them to make design decisions regarding formal geometries and material textures at a small scale.

VALUES OF PRE-DESIGN VISUALIZATION

Pre-design visualization redefines and repositions architectural visualization by prioritizing the generation and utilization of real-time rendered images as basic evaluative means in the looping, iterative process of architectural design. It produces interactive media that merge formal, visual, and quantifiable design information, eliminating cognitive barriers in the conventional design process (see Chen 2004) and nurturing a "warm bed" for idea generation and interdisciplinary communication. Its adoption by architects will provoke a restructuration of designer-media relationship in many design activities in favor of design evaluation, communication, and user participation.

Self-Reflexivity in Design Thinking

Many architectural design problems, especially those concerning the so-called "above the line" or evident formal design (Dormer 1990) are typical "wicked" problems. These problems are ill framed, with multiple decision-makers with conflicting concerns and priorities (Buchanan 1995). Wicked problems manifest the real-world interdependence of assorted factors, and call for integrated and flexible design solutions (Knox 2011). In practice, experienced designers tend to use an inductive or breadth-first method, developing a range of candidate proposals through an iterative reasoning and conception process to endure the complexity in the problem situation (Razzouk and Shute 2012; Cross 2004). Such a process contains recurring loops as the designer constantly observe, compare, and evaluate contingent results to inform possible adaptions in the earlier generative procedure (Cross 2011; Rowe 1987). Pre-design visualization can radically improve the designer's self-reflexive mental activities in the cyclical design process. All three design games considerably increase the quantity and quality of visual feedback the designer can access for practicing self-reflexivity. Unreal Engine's infusion of real-time visualization and interactive parametric design

Figure 5. Screenshots of Parametric Wall Observer Source: Author.

interfaces positions the designer in "the commander's seat", greatly alleviating the stress of assessing alternate schemes' building performance (e.g., financial and technical validity) and user performance (e.g., visual and behavioral satisfaction). In contrast, conventional post-design visualization strategy elongates the feedback loops linking evaluative data and design generation, rendering self-reflexive activities more cumbersome for architects. As "graphic tools inform and bracket how designers think" and may augment or confine designers' understanding of a design problem (Burns and Kahn 2005, 17), pre-design visualization bolsters the computational support of architectural design process by espousing real-time 3D visualization (See Yildirim and Yavuz 2012; Parthenios 2005).

Interdisciplinary Interaction and Communication

Architects nowadays are practicing in an everchanging design and development industry that features a diversity of project procurement routes, knowledgeable and demanding clients, and increasing organizational complexity of design team (Nicol and Pilling 2000; Larson 1993; AIA 2017; RIBA 2000, 2005; Bos-de Vos et al. 2018). The migrating industrial models call for new professionalism of architecture, which values flexible and reflexive actions in design and sophisticated communicative competence to maintain a relational process that design is co-produced through interactions of diverse professionals (Dent and Whitehead 2002; Emmitt, Prins, and Otter 2009). As the organizational field of design turns more complicated, the challenges mount up for architects to better communicate and collaborate with clients, staff, contractors, engineers, and the public (Xie 2002; Coughlan and Macredie 2002; Norouzi et al. 2015).

The increasing complexity of architectural design projects demands more frequent and effective interaction and communication among various actors and stakeholders in the design team (Habraken 1999; Norouzi et al. 2015). However, the increasing amounts of design knowledge and a widening "cultural gap" between architects and other professionals habitually result in miscommunication among participants of design (Chen 2004). Some empirical studies indicate that 3D visualization can aid design communication (Shen 2012; Shen, Shen, and Sun 2011; Shin et al. 2017) as it draws on human cognitive experiences that are commonly shared among collaborating professionals with different backgrounds. Pre-design visualization acknowledges the centrality of 3D visual imagery in design, possessing inherent advantages for design communication.

In a broader context of contemporary design and building industries, design communication ties intimately to the interdisciplinary design evaluation process that reflects the multiplicity of parties and their requirements (Bonnardel and Sumner 1996; Shin et al. 2017). The evolving concept of Pre-Occupancy Evaluation (PrOE) pronounces evaluation-in-design for mitigating risks and maximizing values. Pre-design visualization can support PrOE through its 3D virtual simulation abilities: non-designers may "test drive" a building proposal in the virtual environment or observe and comment on designers' design exploration. On either occasion, real-time rendered imagery serves as the foundation for mutual understanding.

Public Engagement and Participatory Design

As market forces continually adopt cultural values that promote flexibility and personalization, there has been an ascending momentum in planning and architectural design that advocates user participation and public engagement. Bearing different names such as Public Interest Design (PID), Participatory Design (ID), User-Centered Design (UCD), Universal Design (UD) or Inclusive Design (ID), these scholarly discourses and practices share the interest to involve end-users in a co-creative process of design (Abendroth and Bell 2018; Sanders and Stappers 2008; Sanoff 2000, 1978; Gregory 2003; Sanoff and Toker 2003; Chang and Luh 2012; Bose 2014; Sanders 2002; Fisher 2008; Nussbaumer 2012). Some precedents of user participation employed visual tactics (Al-Kodmany 1999; Buckingham 2009) to trigger sustainable dialogues and facilitate knowledge generation in participatory initiatives (Luck 2003; Yanki 2008). Highlighting interactivity and visual materials, pre-design visualization naturally favors participatory design activities. Architects may empathize users' perspectives and experiences by observing how users respond to interactive media developed to the principles of pre-design visualization. For users, pre-design visualization makes the design process more audible and responsible, aiding the extraction, dissemination, and utilization of users' "experiential knowledge" in design (Moore 2017).

CONCLUSION & RESEARCH DIRECTIONS

With 3D modeling of geometrical definitions and arrangements prioritized as the predominant computational use for architectural design, digital visualization has been relegated to a secondary, post-design role. On the other hand, digital visualization technologies fed by the booming game industry have made great strides in efficiency, quality, and interactivity. Real-time rendered procedural objects in today's video games (e.g., an operable door or a customizable building system) assist gamers to competently understand, manage, and respond to complex situations, yielding satisfactory gaming experiences (Walfisz, Zackariasson, and Wilson 2006). Game developers' pursuit of interactive imagery indicates a wider context of techno-cultural changes that pictures become vehicles of storage, manipulation, and communication of information (Lopes 1996).

The availability of sophisticated visualization technologies and the rising importance of high-quality imagery are not matched by a methodical search for the improvement of architectural visualization (Koutamanis 2000). Some studies encourage the adoption of game technologies (e.g., Schroeder 2011) but suggest no methodological revision. Foregrounding the use of real-time 3D imagery, pre-design visualization overcomes the structural limitation of post-design visualization. Pre-design visualization introduces unified, interactive design media that visualize a multitude of evaluative information in real time for designers to initiate, appraise, and develop parametric design objects, while conventional design media either visualize fixated 3D models or provide adaptivity in modeling without any built-in visualization procedure. Through three exemplar Unreal Engine design games, the present study demonstrates several unique advantages of pre-design visualization.

While commercialized software products of pre-design visualization are still unavailable and, therefore, impossible to assess, using Unreal design games as interim solutions already illuminates some meaningful research directions. First, there is a necessity to standardize a digital workflow whereby design games can exchange data with existent architectural design programs. Currently, all three design games adopt a simple additive algorithm for procedural modeling. Designed forms in the games are accumulations of basic mesh components of varied types in different materials, locations, scales, and rotations. The games can document and export these data to EXCEL worksheets for interoperation with common parametric design applications such as Grasshopper for Rhino or Dynamo for Revit. Standardization of such a workflow should streamline the data transfer and conversion procedure for Unreal games' dynamic "upstream" (from the game to other applications) or "downstream" (from other applications to the game) integration with Rhino and Revit in different design stages. The workflow should also support other modeling algorithms, for example, spline-based procedural modeling for creating curved forms in Unreal games.

Second, pre-design visualization should incorporate more compelling visual and behavioral simulation functions for architects or other stakeholders to perform accurate predictive assessments. Digital design simulation could collect simulated behavioral data from a user-controlled avatar (Oerter et al. 2014) or an autonomous character that acts like an actual user (Shin et al. 2017). Unreal Engine supports both approaches, but the three design games only simulate user behaviors through manual inputs. Ideally, interactive design media for pre-design visualization should resemble an open-world multiplayer game, involving several user-controlled avatars as well as some Non-Player Characters (NPC) controlled by Artificial Intelligence (AI) to simulate complex person-environment interactions in the designed space. Moreover, extra sensor technologies (e.g., eye-tracking devices) may be employed as add-ons to measure detailed aspects of simulated behaviors like visual attention, elevating computer-aided design (CAD) to a new horizon where designers create and study 3D digital forms with a constant cognizance of their probable user implications.

Finally, pre-design visualization methods should overcome some real-world logistic barriers when applied in community-based participatory design initiatives. The exemplar design games require Windows operating system with DirectX 11 support. They also need at least an entry-level discrete Graphics Processing Unit (GPU) (e.g. Nvidia MX150) to run smoothly and input devices of a keyboard and a mouse device for user interactivity. These software and hardware requirements may not be available in all participatory design situations. Therefore, a scalable deployment strategy is a prerequisite for broader public access to media of pre-design visualization. For example, the same design game can be deployed to different platforms: standalone applications on computer, apps on mobile devices, or web-based applications with varying graphics qualities and interactive functions. Endeavors to build design media for their assimilation in users' everyday realm cultivate architects' sensitivity toward user needs and help remove cultural obstacles between architects and end-users.

ENDNOTES

1. With a combined revenue of $152 billion in 2019, the contemporary global gaming market is larger than the music and film industries combined. Such a growing market stimulates the development in hardware and software technologies in 2D and 3D graphics. For example, the computing performance of Nvidia GPU (Graphics Processing Unit) measured by double precision FLOPS (Floating-Point Operations Per Second) has surged by some seven times since 2012.
2. Panoramic rendering typically demands a display resolution greater than 4K UHD (3840×2160) or even 8K UHD (7680 × 4320). Mainstream VR headsets produces images at 1440×1600 for each eye (2880×1600 combine pixels).
3. In the foreseeable future, the innovative Real-Time Raytracing (RT) technology will further improve the rendering quality, making real-time imagery a more trustworthy visual evidence for representing lighting and material.
4. 3D procedural software such as Houdini enables game developers to generate countless unique-looking artifacts with a small number of procedural scripts.
5. The current version of the game uses fixed parameters for modular apartment and parking units, limiting the adaptivity of massing schemes to develop. Future versions will introduce more variable parameters for module types and dimensions.
6. For instance, the designer may determine through the console menu that the setback distance of a ground floor storefront is associated with the contingent sightline angle of the human character toward the building façade. Therefore, the storefront is automatically offset to a specific distance according to the character's azimuth relative to the building.
7. To ensure the visual simulation results accurately displayed on a computer monitor, there are minimal display resolution requirements for different screen sizes and viewing distances. For a typical desktop 24" monitor viewed from about 50 centimeters away (1.64 feet), a minimal resolution of 1920×1080 is needed (effective pixel density of 96 PPI) to ensure neighboring pixels' angular distance is smaller than human eyes' angular resolution.

REFERENCES

1. Abendroth, Lisa M., and Bryan Bell. 2018. *Public Interest Design Education Guidebook: Curricula, Strategies, and SEED Academic Case Studies*. New York: Routledge.
2. AIA (American Institute of Architects). 2017. "Foresight Report 2017." AIA. Accessed Septemner 15, 2019. http://content.aia.org/sites/default/files/2017-04/AIAForesightReport2017.pdf.
3. Al-Kodmany, K. 1999. "Using Visualization Techniques for Enhancing Public Participation in Planning and Design: Process, Implementation, and Evaluation." *Landscape and Urban Planning* 45: 37–45. https://doi.org/10.1016/S0169-2046(99)00024-9.
4. Bonnardel, Nathalie, and Tamara Sumner. 1996. "Supporting Evaluation in Design." *Acta Psychologica* 91 (3): 221–44. https://doi.org/10.1016/0001-6918(95)00057-7.
5. Bos-de Vos, M., B. M. Lieftink, L. Volker, Jasper Kraaijeveld, K. Lauche, Armand Smits, L. L. L. Tjoa, and J. W. F. Wamelink. 2018. *Future Roles for Architects: An Academic Design Guide*. Delft: TU Open.
6. Bose, Mallika. 2014. *Community Matters: Service-Learning in Engaged Design and Planning. Earthscan Tools for Community Planning*. London: Routledge.
7. Buchanan, Richard. 1995. "Wicked Problems in Design Thinking." In *A Design Issues Reader*, edited by Victor Margolin and Richard Buchanan. Cambridge, MA: MIT Press.
8. Buckingham, David. 2009. "'Creative' Visual Methods in Media Research: Possibilities, Problems and Proposals." *Media, Culture & Society* 31 (4): 633–52. https://doi.org/10.1177/0163443709335280.
9. Burns, Carol, and Andrea Kahn. 2005. "Why Site Matters." In *Site Matters: Design Concepts, Histories, and Strategies*, edited by Carol Burns and Andrea Kahn, 7–23. New York: Routledge.
10. Chang, Chia-Ling, and Ding-Bang Luh. 2012. "User as Designer: A Design Model of User Creativity Platforms." *Journal of Integrated Design & Process Science* 16 (4): 19–30. http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=85303221&site=ehost-live.
11. Chen, Liang. 2004. "Architectural Visualization: An Analysis from Human Visual Cognition Process." http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=97C3D694331136A6514EF8D6F8B6289F?doi=10.1.1.135.3081&rep=rep1&type=pdf.
12. Coughlan, Jane, and Robert D. Macredie. 2002. "Effective Communication in Requirements Elicitation: A Comparison of Methodologies." *Requirements Eng* 7 (2): 47–60. https://doi.org/10.1007/s007660200004.
13. Cross, Nigel. 2004. "Expertise in Design: An Overview." *Design Studies* 25 (5): 427–41. https://doi.org/10.1016/j.destud.2004.06.002.
14. Cross, Nigel. 2011. *Design Thinking: Understanding How Designers Think and Work*. New York: Bloomsbury.
15. Dent, Mike, and Stephen Whitehead. 2002. Managing Professional Identities: Knowledge, Performativity and the "New" Professional. London: Routledge.
16. Dormer, Peter. 1990. *The Meanings of Modern Design: Towards the Twenty-First Century*. New York: Thames and Hudson.
17. Emmitt, Stephen, Matthijs Prins, and Ad den Otter. 2009. *Architectural Management: International Research and Practice*. Chichester, U.K: Wiley-Blackwell.
18. Fisher, Thomas. 2008. "Public-Interest Architecture: A Needed and Inevitable Change." In *Expanding Architecture: Design as Activism*, edited by Bryan Bell and Katie Wakeford, 8–13. New York: Metropolis Books.
19. Gregory, J. 2003. "Scandinavian Approaches to Participatory Design." *International Journal of Engineering Education* 19: 62–74. http://excelsior.sdstate.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsbl&AN=RN126412770&site=eds-live.
20. Habraken, N. John. 1999. "Notes on a Network Profession [Forming Place, Informing Practice]."
21. Hauschild, Moritz. 2011. *Digital Processes: Planning, Design, Production*. Edited by Rüdiger Karzel and Cornelia Hellstern. Munich: Institut fur internationale.
22. Knox, Paul L. 2011. "Design, Designer, and the Resurgent Metropolis." In *Cities and Design*, edited by Paul L. Knox, 38–61. London: Routledge.
23. Koutamanis, Alexander. 2000. "Digital Architectural Visualization." *Automation in Construction* 9 (4): 347–60. https://doi.org/10.1016/S0926-5805(99)00018-7.
24. Larson, Magali Sarfatti. 1993. *Behind the Postmodern Facade: Architectural Change in Late Twentieth-Century America*. Berkeley, CA: University of California Press.
25. Lopes, Dominic. 1996. *Understanding Pictures*. Oxford Philosophical Monographs. Oxford: Oxford University Press.
26. Luck, Rachael. 2003. "Dialogue in Participatory Design." *Design Studies* 24 (6): 523–35.
27. Martens, Bob, and André Brown. 2005. "Computer Aided Architectural Design Futures 2005." *Proceedings ot the 11th International CAAD Futures Conference*. Dordrecht, NL: Springer.
28. Moore, Steven A. 2017. "Knowledge, Education, Power and Production: Public Interest Design in North America." *Journal of Architectural Education* 71 (1): 46–55.
29. Nicol, David, and Simon Pilling. 2000. "The Changing Context of Professional Practice." In *Changing Architectural Education: Towards a New Professionalism*, edited by David Nicol and Simon Pilling, 27–40. London: E & FN Spon.
30. Norouzi, Nima, Maryam Shabak, Mohamed Rashid Bin Embi, and Tareef Hayat Khan. 2015. "The Architect, the Client and Effective Communication in Architectural Design Practice." *Procedia—Social and Behavioral Sciences* 172 (C): 635–42. https://doi.org/10.1016/j.sbspro.2015.01.413.
31. Nussbaumer, Linda L. 2012. *Inclusive Design: A Universal Need*. New York: Fairchild.

32. Oerter, John, Wyatt Suddarth, Matthew Morhardt, James Gehringer, Micheal L. McGinnis, Johnette Shockley, and Allison Baysa. 2014. "A System Architecture and Simulation Environment for Building Information Modeling in Virtual Worlds." *Journal of Defense Modeling and Simulation: Applications, Methodology, Technology* 11 (3): 205–10. https://doi.org/10.1177/1548512913504839.

33. Parthenios, Panagiotis. 2005. Conceptual design tools for architects. edited by Spiro N. Pollalis: ProQuest Dissertations Publishing.

34. Porter, Tom. 2000. *Selling Architectural Ideas*. New York: Routledge.

35. Razzouk, Rim, and Valerie Shute. 2012. "What Is Design Thinking and Why Is It Important?" *Review of Educational Research* 82 (3): 330–48. https://doi.org/10.3102/0034654312457429.

36. RIBA (Royal Institute of British Architects). 2000. "Architects and the Changing Construction Industry." *RIBA Journal*.

37. RIBA (Royal Institute of British Architects). 2005. *RIBA Constructive Change: A Strategic Industry Study into the Future of the Architects' Profession*. London: RIBA.

38. Rowe, Peter G. 1987. *Design Thinking*. Cambridge, MA: MIT Press.

39. Sanders, Elizabeth B. N. 2002. "From User-Centered to Participatory Design Approaches." In *Design and the Social Science: Making Connections*, edited by J. Frascara, 1–8. London: Taylor & Francis.

40. Sanders, Elizabeth B. N., and Pieter Jan Stappers. 2008. "Co-Creation and the New Landscapes of Design." *CoDesign* 4 (1): 5–18. https://doi.org/10.1080/15710880701875068.

41. Sanoff, Henry. 1978. *Designing with Community Participation*. Community Development Series 40. Stroudsburg, PA: Dowden, Hutchinson & Ross.

42. Sanoff, Henry. 2000. *Community Participation Methods in Design and Planning*. New York: Wiley.

43. Sanoff, Henry, and Zeynep Toker. 2003. *Three Decades of Design and Community: History of the Community Development Group*. Raleigh, NC: NC State University, School of Architecture, College of Design.

44. Schroeder, Scott. 2011. Adopting game technology for architectural visualization. edited by Clark A. Cory, Nicoletta Adamo-Villani and Phillip Dunston: ProQuest Dissertations Publishing.

45. Shen, Weilin. 2012. A BIM-based Pre-occupancy Evaluation Platform (PEP) for Facilitating Designer-Client communication in the Early Design Stage. edited by Geoffrey Qiping Shen: ProQuest Dissertations Publishing.

46. Shen, Weilin, Qiping Shen, and Quanbin Sun. 2011. "Building Information Modeling-Based User Activity Simulation and Evaluation Method for Improving Designer-User Communications." *Automation in Construction* 21 (1). https://doi.org/10.1016/j.autcon.2011.05.022.

47. Shin, Sangyun, Sangah Jeong, Jaewook Lee, Seung Wan Hong, and Sungwon Jung. 2017. "Pre-Occupancy Evaluation Based on User Behavior Prediction in 3D Virtual Simulation." *Automation in Construction* 74: 55–65. https://doi.org/10.1016/j.autcon.2016.11.005.

48. Walfisz, Martin, Peter Zackariasson, and Timothy L. Wilson. 2006. "Real-Time Strategy: Evolutionary Game Development." *Business Horizons* 49 (6): 487–98. https://doi.org/10.1016/j.bushor.2006.04.001.

49. Xie, Xiaoling. 2002. Communications in construction design. ProQuest Dissertations Publishing.

50. Yanki, Lee. 2008. "Design Participation Tactics: The Challenges and New Roles for Designers in the Co-Design Process." *CoDesign* 4 (1): 31–50. https://doi.org/10.1080/15710880701875613.

51. Yee, Rendow. 2007. *Architectural Drawing: A Visual Compendium of Types and Methods*. 3rd ed. Hoboken, NJ: Wiley.

52. Yildirim, Tayfun, and Arzu Ozen Yavuz. 2012. "Comparison of Traditional and Digital Visualization Technologies in Architectural Design Education." *Procedia—Social and Behavioral Sciences* 51 (C): 69–73. https://doi.org/10.1016/j.sbspro.2012.08.120.