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Exploring the use of a digital twin in theatre stage design

Kirjavainen, Emma*[a]; Kalving, Matilda[a]; Etto, Juri[a], Colley, Ashley[a]

[a] University of Lapland, Rovaniemi, Finland
* emma.kirjavainen@ulapland.fi

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The rapid development of technology has brought new methods and tools to physical space planning, offering opportunities to save time and materials. We present a case study where virtual reality (VR) was used for previsualization in the design of a theater production. A digital twin, i.e., a virtual environment matching the exact dimensions and visual appearance of the physical theatre stage was developed. During the design of the theater production, the potential of the approach was evaluated together with theater design and production experts with different backgrounds. We report that VR can play a useful role in the context of theater production design. Through VR headsets, the stage space was better perceived than with other tools, with those less familiar with the space benefitting the most. However, VR could not completely replace the traditional methods of theater stage design and should be used in conjunction with existing approaches.

Keywords: stage design; digital twin; virtual reality; user experience

1 Introduction

Designing an interactive theatre production poses multiple challenges in terms of the unpredictable and complex use of the stage space. In addition, production teams often have limited access to the stage space before the opening night, making the ideation and planning process difficult. To address these challenges, we investigate the potential of a digital replica i.e. a “digital twin” of the physical stage space. When viewed through a virtual reality (VR) headset, the digital twin can help theatre stage designers and production teams plan and ideate interactive theatre productions more effectively. In our study, the physical theatre space was replicated as a digital model. The digital model did not dynamically exchange data with the physical space but served as a creative tool and a means of communication for those working on the theater production (Fuller et al., 2020). Interactive theatre involves breaking the traditional “fourth wall” that separates performers from the audience, both physically and verbally. By doing, so audience members gain the ability to actively influence the course of a scene. This often requires actors to improvise lines and to utilize the theatre space in unexpected and spontaneous ways. In a case study, run during the planning and design phases of an interactive theatre production, we created an accurate VR model of the physical theater space and tested its use as a design tool by professional production designers. Our results indicate that VR and the developed

3D models played a crucial role in the staging team's workflow. The participants reported that the use of the digital twin allowed them to visualize the design in a more realistic and immersive way, helping them to identify potential problems and make adjustments before the actual execution of the project. The digital twin also facilitated communication and collaboration among the team members, as it enabled them to share a common understanding of the design. Our findings highlight the potential benefits of using VR modeling in design processes in the theatre industry. This research also contributes to the broader discussion on the use of technology in the arts, particularly in terms of its impact on creative processes and production outcomes.

2 Background and related work

To provide background to our work we first summarize the typical theatre production design process and then review prior work where digital twins and VR tools have been used in space planning and pre-visualization, particularly in theatrical domains.

2.1 Theatre production design process

Theatre production involves various teams working independently towards a shared goal. Set design and script-based production, for instance, are conducted separately, with actors rehearsing off-stage before the final assembly. Disciplines like film, animation, and theatre rely on a detailed planning phase, known as previsualization (previs), to explore ideas, plan technical solutions, and communicate a shared vision (Okun & Zwerman, 2010). Previs is a key part of pre-production, aiding in cost-efficient scene and shot planning (Ardal et al., 2019). However, in theatre, most of the team doesn't see the staging until final rehearsals, despite some previsuals like sketches being shared earlier.

2.2 Virtual reality and digital twins for production planning

VR is a medium characterized by its interactivity, spatiality, and real-time nature (Whyte, 2002). Dixon (2006) provides an overview of the use of VR in the performing arts, including works that recreated of ancient theatres in VR. Its potential as an architectural design tool was recognized early on (Brooks, 1993), and it has since found applications in various fields, including the performing arts. Dixon (2006) provides an overview of VR's use in recreating ancient theatres, among other applications.

Although prior work on digital twins has predominantly focused on manufacturing systems, the value of the approach in socio-technical design has been noted (Barricelli, Casiragh & Fogli, 2019). The integration of VR and digital twins has opened up new possibilities for production planning in various industries. In the film industry, previs commonly utilizes professional 3D modeling software packages such as Maya, Blender, or Unity3D. With such tools, creatives can quickly iterate and refine their ideas with high accuracy and detail, resulting in a more polished final product (Nitsche, 2008). The use of VR-based tools for film and theatre previsualization tasks has been reported as beneficial, especially for non-technical personnel who can naturally explore the build space (Muender, Fröhlich, & Malaka, 2018; Muender et al., 2019).

Volkmar et al. (2020) developed the NUI tool which provided a shared VR space for performing previs tasks. Users can move freely within the virtual environment and directly manipulate objects using VR hand controllers. This immersive and intuitive approach facilitates collaboration and visualization, making the previs process more seamless and efficient (Volkmar et al., 2020). The use of VR in theatre rehearsals has also been explored. Levordashka et al. (2023) reported benefits in performers' spatial

understanding and suggested the creation of a database of 3D models of theatre stages and props. Similarly, Colley et al. (2015) found that using a VR headset to explore a virtual environment in the design process of an industrial site was preferred over viewing the 3D model on a screen.

Although emerging technologies such as VR offer new opportunities for creative work, it is crucial to have a good understanding of the tool's features and controls to fully benefit from its positive effects. In their study exploring VR tools in design education, Häkkilä et al. (2018) report that it is essential to look beyond the effects of novelty and unfamiliarity with the technology to recognize its long-term value.

3 Case study: Theatre stage production

To gain an understanding of the strengths and weaknesses of VR and digital twin techniques as part of theatre stage design, the research team engaged with a theatre production at the beginning of its planning process.

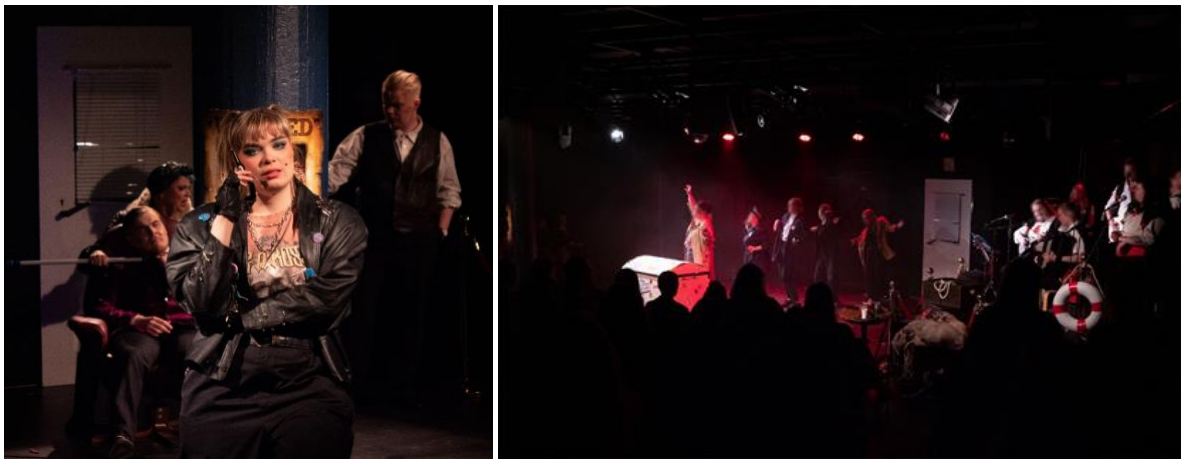

Figure 1: The final stage production

3.1 Case study setting

The study involved the integration of the research personnel with the production team of the interactive theatrical production of [anonymized] at [anonymized] theatre during the spring of 2023 (Figure 1). The performance took place on the [anonymized] stage with a stage area of 62.5 m2. Furthermore, during certain segments of the play, the actors made use of both the seating and backstage areas. The total production budget, excluding salaries, was approximately 17,000 euros. The production team consisted of approximately 80 people, including 8 actors, 4 dancers, and 6 band members.

The staging team first mapped the available space from preliminary measurements of the stage area and based on the needed elements and the material constraints, made rough plans for the stage flats. These were created as paper sketches which were used as the guidelines when designing the final structural plans for the flats using more accurate measurements.

3.2 Development of the digital twin environment

The digital twin of the stage environment was built by taking detailed measures of the theatre space and creating a dimensionally accurate model using Autodesk Fusion 360, with VR development in

Unreal Engine 5 (Figure 3). Numerous photographs were taken both for reference and to use as materials for object surfaces in the game engine. Based on discussions with the staging team, the necessary level of detail required in the digital twin was established. The stage and backstage areas were mapped to within +/-1 cm, including electrical boxes, pillars, and a movable stage for the band. The audience seating areas were modeled with lower accuracy. The staging flats themselves were modeled based on the staging team's plans and the wishes of the production team.

The VR environment itself was built in Unreal Engine 5 (UE5), using the built-in VR template. The model of the stage was imported to UE5 and processed and textured to be game ready using the built-in post-processing and texturing tools in the engine. This streamlined the development process, eliminating the need for separate texturing software. With the stage base ready, the staging flats were then designed with the help of the VR model, with subsequent iterations being tested and fine-tuned in VR.

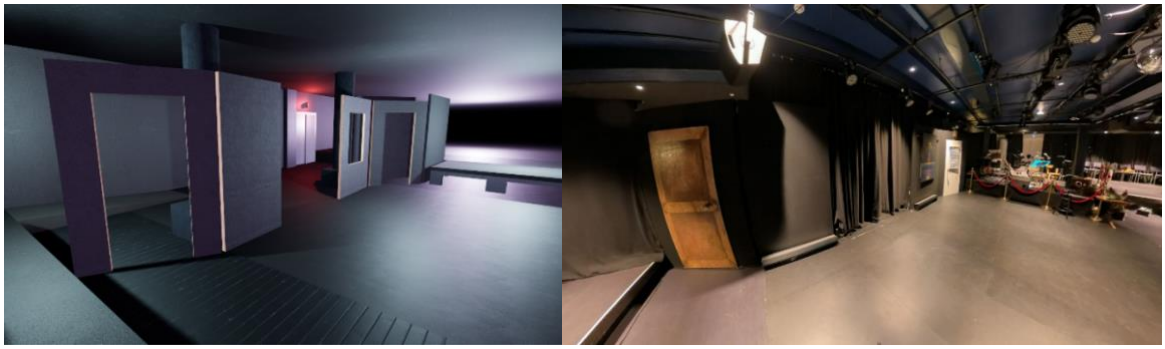

Figure 2: Left: Virtual reality stage environment. Right: Real-world stage

3.3 Workshop with the theatre production team

The initial phase of the study was carried out during a weekend at a workshop organized by the theatre production team, with the aim of introducing the entire production team to the diverse aspects of the production. The workshop was attended by the entire production team, which included actors, videographers, and staging personnel. At the workshop, the set designers employed a range of resources, including VR headsets to view the developed digital twin of the stage, cardboard, tape, 3D printed models, photos, and blueprints (Figure 5). Although the company had used mock-ups in previous productions, the digital twin and VR experience was a new concept for this production company.

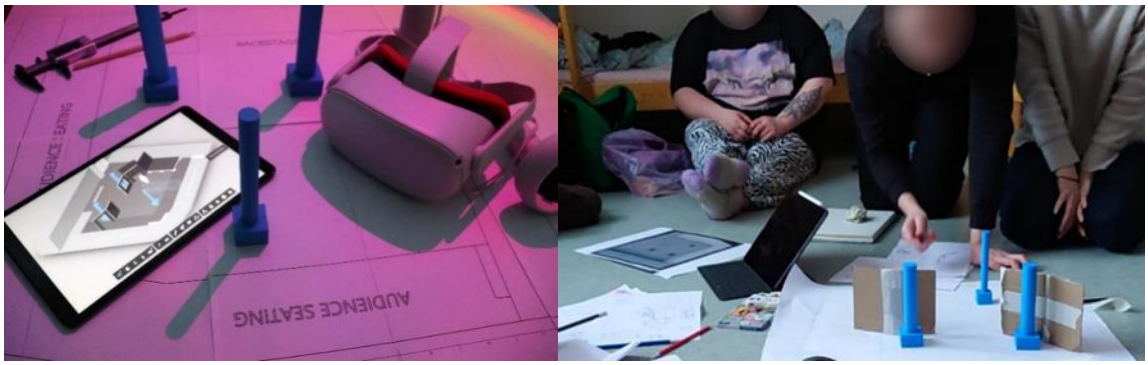

Figure 3: Left: Materials used in the workshop; stage base map, 3D model, miniature models of columns, and VR equipment. Right; Workshop participants.

3.4 End survey and interviews

Data collection consisted of a survey and follow-up interviews with the stage designers and production team members who had utilized the digital twin during the planning process. The survey was conducted in connection with workshop participation, during which the participants' experience of using the digital model as an aid in design work and communication was still fresh and up-to-date. The survey explored the effectiveness and added value of using VR for stage design planning, in terms of time and resource management, creativity, and the overall design process.

Upon completion of the survey analysis, we conducted individual semi-structured interviews to gain further qualitative insights. These interviews provided participants with an opportunity to reflect on and vocalize their experiences. Each interview, lasting between 15 to 25 minutes, was recorded for subsequent analysis. These interviews were scheduled post-premiere, ensuring that participants had firsthand experience with both the design process and the final set design. After the interview, participants were asked an open-ended question to encapsulate their impressions of using VR in the set design process. They also completed the System Usability Scale (SUS) questionnaire, providing an assessment of the VR system's usability. A total of six participants took part in both the survey and the interviews.

4 Findings

During the workshop, it was noticed that participants needed some time to get accustomed to using the VR headset, requiring guidance not only in using the VR headset but also in navigating VR. Overall, the use of the VR headset was seen as a positive experience in this context. The digital twin model was perceived as a useful tool for collaboration between the set design team, actors, and choreographers. With the help of the model, theater staff could discuss the perception of the stage space and its use in terms of movement on stage and the placement of sets. The VR tool was seen as an effective communication tool that allowed for joint discussions and testing of plans in advance. Therefore, it was perceived to reduce the time needed to design the physical space and make iterative changes. However, traditional methods were considered more useful in terms of experiencing the space simultaneously as a group. Although we had several VR headsets available during the workshop, not all participants could enter the virtual theater space simultaneously.

Based on the survey results, it was revealed that none of the participants had their own VR headsets (0/6), but all of them owned smartphones (6/6) and laptops (6/6). Half of the respondents owned a tablet (3/6), and one participant had access to a smartwatch (1/6). Despite none of the participants having prior experience with VR tools in theater production design or specific expertise in using them, they generally viewed the VR model very positively. The visualization of the space and the agility in testing ideas, particularly in set design, were highlighted as positive aspects. The possibility of space planning was also mentioned, and considered advantageous in terms of costs, schedules, and space reservation. The digital twin and VR experience significantly impacted the workflow of the set design team. The survey results were analyzed by creating an affinity diagram to classify the key themes mentioned in the responses. The survey revealed three main themes: space visualization, usability, and user experience.

The follow-up interviews further substantiated the advantages of employing the digital model in this project. As depicted in the table derived from interview responses (see Table 1), presenting the digital

twin model via VR allowed the staging team to demonstrate the project to the rest of the production team at an earlier stage. This early visualization significantly improved the overall cohesiveness of the production's visual outlook.

Table 1. The main themes that emerged during the interview and the benefits and challenges experienced within them in the usability of the digital twin model and 3D model in theatre production

	Set Design	**Cooperation within the theater production team**	**Financial**	**Experiencing the space through the virtual model**
Benefits:	Using and viewing space remotely.	Help with communication	The possibility of unlimited testing	An inspiring experience
	Helps in designing and testing sets.	Enhancing the transparency of the design process.	Limitless accessibility of space	Authentic experience
	Observing the scale of the space is much easier.	A functional tool for planning and organizing work tasks.	Save material, time, and money	Help in visualizing and observing the space.
		Unifies the entire work group		Helped work
Challenges:	No sense of materials	Using technology requires skills and time	Using technology requires new equipment and money	No sense of touch
	Does not completely replace the experience of using physical space and model.			Does not completely replace the experience of the physical space.
				Unauthentic experience

The participants reported that the use of VR and 3D models reduced the time and cost compared to the traditional design process. The traditional process involved the creation of physical mockups, which were time-consuming and expensive to produce. However, with the use of VR and 3D models, the team was able to create a virtual mockup before any material was used, which was more cost-effective. The five participants who used the VR tools more extensively gave it a median system usability (SUS) score of 72.5 (A SUS score above 68 is considered above average, while a score below 50 is considered below average). This suggests that the VR tools were both useful and usable, without major problems.

Participants who were already familiar with the theater space mostly used the 3D model on a computer or smartphone. However, new workshop team members, who had not previously seen the physical space, were more actively engaged in exploring the model using the VR headsets. This suggests that the digital twin model of the space was perceived as interesting, especially for those participants who had not experienced the physical space before. The spatial understanding was

clearer and easier with the digital twin model compared to the 3D model. Through the digital twin model, the space was perceived as more three-dimensional and distinct, which was seen as positively facilitating spatial comprehension.

Participants reported conflicting levels of realism for the VR experience. Whilst some felt it was very realistic and admired its similarity to reality, others believed that the VR could not provide the same feeling as reality. VR and reality were perceived to complement each other in terms of space modeling and experiencing the space. The theater group had previously used physical miniature models as an aid in stage design, but in the future, felt that this could be replaced, at least partially, by VR.

5 Discussion

Our results indicated that while there was initial excitement and interest in using VR to experience the stage set, the 3D model viewed on a laptop or phone was more frequently utilized. This is perhaps indicative of the lower accessibility of the VR headset. Laptops and mobile phones and computers are quicker, easier, and more acceptable to use in different places such as the hardware store when purchasing materials. However, it was also mentioned that VR could be particularly beneficial for individuals who feel anxious in foreign spaces and would feel comforted by pre-knowledge of the exits and the atmosphere.

Some participants explored futuristic visions, such as VR and 3D models completely replacing the use of small-scale models in theatre production set design. One particular driver for this is that textures can be more easily replicated in VR than in small-scale models, providing a more accurate representation of the final product. One participant identified a potential benefit of using VR in rehearsals, allowing actors to rehearse in a combined virtual space that was built around the stage. This would provide a more immersive rehearsal experience and facilitate the exploration of different performance possibilities.

It is important to acknowledge that the VR or 3D model did not replace the need for a physical visit to the theatre, but rather provided a preview or pre-taste of the final product. A physical visit allows the exploration of different perspectives, angles, and safety routes, which were limited in the virtual environment. The use of these technologies should be viewed as complementary to the traditional design process, providing a more accurate and efficient design option. New technologies and tools have the potential to bring about many new possibilities in the planning and execution stages of the creative process. However, a significant challenge arises from the lack of proficiency and experience in handling these novel technologies. In this case, the utilization of the VR model would have not been possible without the research team’s know-how in constructing the virtual spatial model and instructing on the usage of VR headsets.

As future work, we are interested in exploring how VR can be integrated more extensively into actors' work and rehearsals. This technology offers a unique opportunity for spatial perception and its application in various tasks related to theater productions. We believe that further research is necessary to fully understand the potential of VR in this context.

6 Conclusion

VR and 3D models can play a valuable role in the theater production workflow, to illustrate plans and perceive space. Our findings suggest that the use of such digital twins can enhance the design process, improve communication and collaboration among team members, and reduce the time and cost associated with the traditional design process. However, such tools cannot fully replace the traditional methods such as using small-scale models and visits to the physical stage space, and should be used as a complementary tool.

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