Creating, Testing and Evaluating Immersive Virtual ICU-CCU Built Environments

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2022 European Healthcare Design Conference, London, UK

Acknowledgements

The authors wish to acknowledge the major contribution to this presentation and the IVE research initiative provided by the collaborating team at UBiSOFT Toronto in 2022: Istvan Tajnay, Vincent Pontbriand, Jorge Freitas, Corey Barnard, Bruno Tiburcio, Thaiago Larenas Faria, Mandi Matson, Peter Handrinos, Christian Carriere, Kiersten Samwell, Lauren Bartley, Courtney Grey, Sia Eftekharifar, Karen Stanley, Guy Burkhart, Ben Liaw, Kieran O’Sullivan, Michael McCliment, Graham Allsop, Alex Halliwushka, Justin Del Giudice, and Emily Claire Afan. Thanks also to research assists from Lucas Siemucha and Catherine Dela Cruz, M.Arch Candidates at the University of Toronto.

Introduction

The recent ICU-CCU evidence-based built environment literature (2005-2022) expresses a typology of nine primary areas of concern:

Nature engagement and outdoor views —The influence of exposure to nature as well as representations of nature, with focus on measures of stress reduction outcomes;

Family accommodations in the ICU-CCU environment —The role of family involvement and the influence of family input in unit design and amenities provided;

Spatial configuration and amenity —Physical layout, staff affordances, proxemic relationships, i.e., staff travel distances, sight lines, single versus semiprivate rooms;

Noise considerations —Deleterious effects of noise and involuntary distractions on patient and staff well-being, patient delirium, and noise mitigation measures on occupant outcomes;

Artificial and natural lighting —Adverse effects of excessive light on occupant well-being, the benefits of informative views, ventilation, ambient light levels on patient outcomes;

Patient safety and infection control —Types and prevalence of adverse medical events in ICU-CCUs, mitigation, and improving patient outcomes;

Portable field hospitals and disaster mitigation including COVID-19 —Functionality of hospital adaptations and redeployable field hospitals in natural disasters and in COVID-19;

ICU-CCU ecological sustainability—Recent advancements in energy efficiency, materiality, facility design and daily operations;

Recent and prognosticated design trends—Therapeutic design affordances and unit performance optimization.

What are IVEs?—*Immersive Virtual Environment* (IVE) simulation represents a breakthrough method to test and assess the appropriateness of unbuilt (pre-occupancy) as well as built (post-occupancy) healthcare physical environments. However, this technology is yet to be used as a facility planning, design, or evaluative tool in hospital-based ICU-CCU settings in either context.

The aims of this presentation are:

1. **To review recent IVE research in healthcare contexts in the context of the broader recent ICU-CCU literature, comparing/contrasting studies from the end user's perspective (see References provided at conclusion),**

2. **To assess interdisciplinary IVE strategies as a design visualization tool in ICU-CCU settings, drawing from a recent exploratory pilot project between SickKids, UbiSoft Toronto, and the University of Toronto's *Centre for Design + Health Innovation*.**

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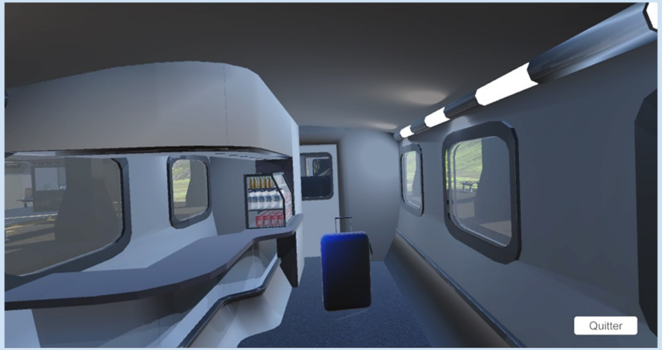
1. Crafting Virtual Space

Intent:

The intent of this pilot collaboration was to outline the features needed to create or license a Unity plugin for use in evaluating multiple ICU-CCU unit design scenarios for pre-testing in a virtual environment with a high level of representational accuracy. This plugin will allow multiple design scenarios to be comparatively evaluated by ICU-CCU direct care providers. Unity plugins recommended include *Floor Map Designer—Realtime Procedural Rooms Editor*.

Virtual Space Requirements:

- The spatial configuration toolset is to consist of basic architectural elements that can be modified to represent an existing scape or a proposed space, based on to-scale drawings.
- Wall thicknesses should be thick enough to support lighting and light bleeding issues (15-30cm).
- Door frames should support double and single frame sizes.
- Doors should be included and interactive.
- Windows should be free form scalable as there are many non-standard window aperture sizes in ICU-CCU settings.
- Floors, walls and ceilings should have drag/drop capabilities.



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1. Crafting Virtual Space (Cont.)

Props Requirements:

- Props should drag and drop from an *asset library* and not scalable as they are based on real-world measurements.
- A process should be in place to allow new equipment and furnishings (assets) to be added in the future.
- Props should be able to be reasonably picked up and moved, with collisions of objects and avatars noted in the gamespace, i.e. handheld medical equipment, caregivers bumping into one another as well as:
- Varying sizes and types of beds
- Assorted types and sizes of carts
- Different types and positions of monitors and regulators
- Bedside tables and trays
- Other equipment and tools in the room

1. Crafting Virtual Space (Cont.)

Lighting requirements:

- Dynamic external and internal light sources: The sun should be rotatable to match the time of day, light fixtures turn off and on, luminosity and shadows recalculated per frame.

Audio Requirements:

- Audio can be placed in layers to simulate ambient noise, spatial noise and directional noise. Unity's audio function allows full spatialization and propagation. This plugin can be supplemented with Wwise by Audiokinetics. This allows for simulated "real" audio events. Sampled actual audio can ensure parity with real-world events in ICU-CCUs.
- Ambient sound effects (hallway chatter, PA messages, etc.) should be categorized by type (Ambience, Foley, Prop Sounds) and archived so game designers have appropriate sound effects when dropping props in to the virtual gamespace.

Scripting Requirements:

- Scenarios can be created that direct timed actions within the IVE's scripted events. These scripted modules reference props, i.e., a rolling supply cabinet.

2. Navigating Virtual Space

Intent:
Once the IVE spaces are created, the intent is then to allow for gamespace occupants to interact with these IVEs to a degree that closely replicates a *live* ICU-CCU environment. Within the IVE, individuals can use VR movement controls in multiple ways:

- **Smooth**—Avatar movement is the smooth movement that closely simulates walking, with direct control of speed, direction of movement, and orientation of the camera at all times.

- **Blink**—Teleportation movement is a point-to-point experience requiring line of sight which immediately teleports the individual to the new location. This is often preferred by persons subject to VR motion sickness.

- **Shift**—Shift movement, which is a hybrid of the two above, involves the individual selecting a destination point within line of sight, and rather than manually navigating or teleporting, the avatar is translated through the space (*world pulling*).

2. Navigating Virtual Space (Cont.)

Environmental Collision:

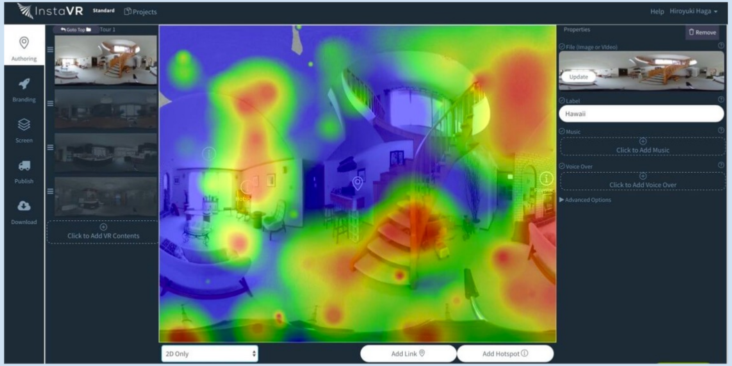
- In IVEs, individuals can bump into fixed and non-fixed objects (props). Collision with a static object (such as a wall) prevents the individual from moving further in that direction and trajectory. Collision with dynamic props will move it a fixed distance in response.

Interpersonal Collision:

- Collision may occur with other individuals, i.e., patient, other participants. This results in a gentle push apart vis-à-vis Teleport and Blink functions.

Heat Maps:

Floorplan heatmaps are a useful metric to document high and low trafficked areas within the IVE. They allow continuous data gathering of what one looks at, for how long, where hands were placed during the session, and where collisions occurred.



3. Participant Interactions Within IVEs

Intent:

Identify and model patient/caregiver interactions in the IVE to simulate actual patient care scenarios. At start of the session, scripted scenarios are presented that can play out in the IVE. These scenarios range from simple vital sign monitoring and blood draw tasks to emergency events required lighting fast team-based decision-making. Sessions should be recorded and reviewed, including assessments of multiple architectural design scenarios.

Game-Within-Game Options:

- These allow for a given event or task to be the sole focus.

AI Applications:

- Higher fidelity IVEs require a "patient" that is AI-driven.
- Examples: The Johnson & Johnson Institute: https://jnjinstitute.com/en-us/virtual-reality.htm and Oxford University: https://oxfordmedicalsimulation.com.htm/

4. Customization

Hand Representation:
In IVEs the individual's point of view is governed by two customizable hands that record dominant hand selection, hand size, and glove type and color. This occurs before start of session and become one's *user profile* (or can be chosen from default options).

Full Body Representation:
Within IVEs, patients, staff, and other individuals can be represented by full avatars that depict:

- Gender representation
- Race
- Height and Build
- Hair color and style
- Facial features
- Clothing type and color
- PPE
- Virtual nametags

5. The Interactive IVE Experience

Intent:

The IVE experience should accommodate a maximum of ten individuals concurrently. Individuals can join or leave the gamespace independently.

Verbal Communication:

- Activated through the VR device’s built-in audio and voice system

Spatial Locomotion:

- Uninterrupted (Smooth mode) versus interrupted movement (Blink and Shift modes) can cause individuals to become out of sync with one another. Note: Complex scenarios with many interacting at once are difficult to simulate.

Metrics:

- Metrics in interactive IVE space focus on **collisions between individuals**, **fixed, and non-fixed objects** (Props). Each collision should be recorded to determine the source. Similarly, **spatial heat maps identify key points and objects of interest**, to verify information and uncover redundancies.

Evidence shows that changes in the architecture, design, and decor of health care facilities can improve patient care and in the long run reduce expenses. These essays detail the state of the research, look inside two hospitals that put some of these innovations into practice, and consider how design fits into the moral mission of health care.

Fable Hospital 2.0: *The Business Case for Building Better Health Care Facilities*

BY BLAIR L. SADLER, LEONARD L. BERRY, ROBIN GUENTHER, D. KIRK HAMILTON, FREDERICK A. HESSLER, CLAYTON MERRITT, AND DEREK PARKER

Despite deep and vocal disagreements over health care reform, virtually everyone believes that the current system is not economically sustainable. We are spending too much and getting too little in return. This recognition has spurred health care leaders to examine every aspect of hospital operations. But what about the health care building itself, the physical environment within which patient care occurs? Too often, cost-cutting discussions have overlooked the hospital structure. Changes in the physical facility provide real opportunities for improving patient and worker safety and quality while reducing operating costs.

The "Fable hospital," an imaginary amalgam of the best design innovations that had been implemented and measured by leading organizations, was an early attempt to analyze the economic impact of designing and building an optimal hospital facility.[1] The Fable analysis, published in 2004, showed that carefully selected design innovations, though they may cost more initially, could return the incremental investment in one year by reducing operating costs and increasing revenues. Reactions to the Fable paper varied. Many felt it presented a compelling case and stimulated health care leaders and architects to think differently about balancing one-time building costs with ongoing operating costs. Others voiced skepticism about whether the benefits were as great as described and asked for more evidence.

Today, the Fable hospital is no longer imaginary. During the past six years, numerous hospitals have implemented many of its attributes and have evaluated their impact on patients, families, and staff.[2] Several are members of the Center for Health Design's Pebble Project, a group of organizations that apply evidence-based designs to improve quality and financial performance. Two Pebble hospitals are featured in essays accompanying this article. These and other pioneering organizations and their architecture/design teams are introducing such interventions as larger single-patient rooms, which reduce the incidence of health care-associated infections; wider bathroom doors, which reduce patient falls; HEPA filtration and other indoor air quality improvements, which reduce health care-associated infections; appropriate task lighting in medication dispensing areas, which reduces medication-related errors; hydraulic ceiling lifts in patient rooms and bathrooms, which reduce patient and staff lift injuries; and art and music, which reduce anxiety and depression and speed recovery.

Since 2004, much has changed that affects decision-making about health care construction and design. It is time for a fresh look at the Fable hospital. Drawing on the latest design and health care knowledge, research, the 2010 health reform law's emphasis on value and quality improvement, and our collective experience, we present Fable hospital 2.0.

The Changing Health Care Landscape

Five major health care trends are relevant to our analysis: the growth of evidence-based design, the safety/quality revolution, pay for performance and increasing consumer transparency, sustainability and green design, and access to capital.

Blair L. Sadler, Leonard L. Berry, Robin Guenther, D. Kirk Hamilton, Frederick A. Hessler, Clayton Merritt, and Derek Parker, "Fable Hospital 2.0: The Business Case for Building Better Health Care Facilities," *Hastings Center Report* 41, no. 1 (2011): 13-23.

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Anticipating the Future

- How to best simulate audio-visual bird’s-eye (overhead) versus ‘on the ground’ (frontal) recording of caregiver team movements and interactions,

- How to best simulate multiple architectural design scenarios of individual rooms versus unit-level simulations in “real time.”

- How to best record heatmaps of spatial hot zones and translate these data for use by architects and allied specialists.

- How to best simulate and assess third person-observer walk-through ghosting, sightline and functional adjacency optimization, room-unit navigation, sensory deprivation conditions, engagement with nature, and family/visitor supports.

- How to best create open access design and health AI-based *libraries* in the metaverse devoted to viewing and learning about IVEs—to improve the salutogenic design quality and functionality of future ICU-CCUs.

References

1. Virtual Reality in Healthcare Settings

1. Ahmadpour, N., Keep, M., Janssen, A., Rouf, A. S., & Marthick, M. (2020). “Design strategies for virtual reality interventions for managing pain and anxiety in children and adolescents: Scoping review.” *JMIR Serious Games*, 8(1), e14565. https://doi.org/10.2196/14565
2. Bayona, Sofia, Espadero, José Miguel, Fernandez, José Manuel, Pastor, Luis & Rodríguez, Angel. (2011). "Implementing virtual reality in the healthcare sector." In *Virtual Technologies for Business and Industrial Applications: Innovative and Synergistic Approaches*, pp. 138-163. IGI Global.
3. Chow, Yang-Wai, Susilo, W., Philips, James G., Baek, Joonsang, & Vlahu-Gjorgievska, Elena. (2017). "Video games and virtual reality as persuasive technologies for health care: An overview." *J. Wireless Mobility Networks Ubiquitous Computing Dependable Appl*. 8(3): 18-35.
4. Dinis, Susana, Duarte, Emília, Noriega, Paulo, Teixeira, Luis, Vilar, Elisângela, & Rebelo, Francisco (2013). "Evaluating emotional responses to the interior design of a hospital room: A study using virtual reality." In proceedings of the *International Conference of Design, User Experience, and Usability*. Berlin, Heidelberg: Springer, 475-483.
5. Dunston, P. S., Arns, L. L., Mcglothlin, J.D., Lasker,G.C., & Kushner, A.G. (2011). “An immersive virtual reality mock-up for design review of hospital patient rooms.” In *Collaborative Design in Virtual Environments. Intelligent Systems, Control and Automation: Science and Engin.,* Wang, X. & Tsai, J.H. (eds.). Dordrecht: Springer, 167–176.
6. Dunston, Phillip S., Arns, Laura L., and McGlothlin, J.D. (2010). "Virtual reality mock-ups for healthcare facility design and a model for technology hub collaboration." *Journal of Building Performance Simulation,* 3(3): 185-195.
7. Jouppila, Tiina, and Tiainen, Tarja. (2021). “Nurses’ participation in the design of an intensive care unit: The use of virtual mock-ups.” *Health Environments Research & Design Journal*, 14(2): 301–312. https://doi.org/10.1177/1937586720935407.
8. Joseph, Anjali, Matthew H. E. M. Browning, and Jiang, Shan (2020). “Using immersive virtual environments (IVEs) to conduct environmental design research: A primer and decision framework.” *Health Environments Research & Design Journal,* 13(3): 11–25. https://doi.org/10.1177/1937586720924787.
9. Kamiska, Dorota, Zwolińsksi, G., Laska-Leśniewicz, Anna, &Pinto Coelho, L. (2022). "Virtual reality in healthcare: A survey." In *Emerging Advancements for Virtual and Augmented Reality in Healthcare*, pp. 1-10. IGI Global.

References (cont.)

2. Design Process Applications

1. Berg, M C., Hartmann, T. & and Graaf, R.S. (2017). "Supporting design reviews with pre-meeting virtual reality environments." *Journal of Information Technology in Construction,* 22(4): 305-321.
2. Bruno, Fabio, & Muzzupappa, M. (2010). "Product interface design: A participatory approach based on virtual reality." *International Journal of Human-Computer Studies*, 68(5): 254-269.
3. Bu, Lingguo, Chun-Hsien, Chen, Kam KH Ng, Zheng, P., Guijun, Dong, and Heshan, Liu. (2021). "A user-centric design approach for smart product-service systems using virtual reality: A case study." *Journal of Cleaner Production* 280: 124413.
4. Kalantari, S., & Neo, J. R. J. (2020). "Virtual environments for design research: Lessons learned from use of fully immersive virtual reality in interior design research." *Journal of Interior Design*, 45(3): 27-42. https://doi.org/10.1111/joid.12171
5. Kumar, Sonali, Hedrick, Matthew, Wiacek, Christopher & Messner, J.I. (2011). “Developing an experienced-based design review application for healthcare facilities using a 3D game engine.” *J. Inf. Technol. Constr*. 16(2): 85-104.
6. Lach, E., Benek, I., Zalewski, K., Skurowski, P., Kocur, A., Kotula, A., Macura, M., Pamula, Z., Stankiewicz, M., & Wyrobek T. (2019). *Immersive Virtual Reality for Assisting in Inclusive Architectural Design*. ICMMI.
7. Qiao, Yu, and Yang, Sigi. (2019). "Healthcare design based on virtual reality technology: Enhance the user’s engagement in the rehabilitation process." In *Proceedings of the International Conference on Applied Human Factors and Ergonomics*, pp. 409-415. Springer, Cham.
8. Spallone, Roberta (2017). "In the space and in time. Representing architectural ideas by digital animation" *Proceedings 1*, 9(2): 962. https://doi.org/10.3390/proceedings1090962
9. Sateei, Shahin, Eriksson, J., Roupé, M., Johansson, M. & Lindahl, G. (2021). "How Virtual reality is used when involving healthcare staff in the design process." In *Proceedings of the CIB Conference W78*, pp. 11-15.
10. Wenting, Li, & Samuelson, H. (2020). “A new method for visualizing and evaluating views in architectural design,” *Developments in the Built Environment*, 1(3): 100005, ISSN 2666-1659, https://doi.org/10.1016/j.dibe.2020.100005.

References (cont.)

3. Comparative Virtual Reality Assessments

1. Heydarian, A., Carneiro, J.P., Gerber, D., Becerik-Gerber, B., Hayes, T., & Wood, W. (2015). "Immersive virtual environments versus physical built environments: A benchmarking study for building design and user-built environment explorations." *Automation in Construction,* 54(3): 116-126.
2. Delgado, J.M.D., Oyedele, L., Demian, P., & Beach, T. (2020). “A research agenda for augmented and virtual reality in architecture, engineering and construction,” *Advanced Engineering Informatics*, 45(1): 101122, ISSN 1474-0346, https://doi.org/10.1016/j.aei.2020.101122.
3. McLaughlan, Rebecca, & Liddicoat, Stephanie. (2018). "Evidence and affect: Employing virtual reality to probe what’s missing from evidence-based design research." *Design for Health*, 2(2): 285-304.
4. Wahlström, Mikael, Aittala, Miika, Kotilainen, Helina, Yli-Karhu, Tiina, Janne Porkka, Janne, & Nykänen, Esa. (2010). "CAVE for collaborative patient room design: Analysis with end-user opinion contrasting method." *Virtual Reality* 14(3): 197-211.
5. Wingler, Deborah, Joseph, Anjali, Bayramzadeh, Sara, & Robb, Andrew. (2020). "Using virtual reality to compare design alternatives using subjective and objective evaluation methods." *Health Environments Research & Design Journal,* 13(1): 129-144.

References (cont.)

4. Evidence-based Research Directions in IVEs

1. Bullinger, Hans-Jörg, Bauer, Wilhelm, Wenzel, Günter & Blach, Roland. (2010). "Towards user-centered design (UCD) in architecture based on immersive virtual environments." *Computers in Industry,* 61(4): 372-379.
2. Rwamamara, Romuald, Håkan, Norberg, Olofsson, Thomas, & and Lagerqvist, Ove. (2010). "Using visualization technologies for design and planning of a healthy construction workplace." *Construction Innovation*, 12(2):14-29.
3. Stinson, L. (2022). “How will the metaverse be designed?” *Metropolis*. January 24, https://metropolismag.com/viewpoints/what-will-our-virtual-reality-be.
4. Whyte, Jennifer, & Nikolić Dragana (2018). *Virtual Reality and the Built Environment*. London: Routledge.
5. Zhang, Yuxuan, Hexu, Liu, Shih-Chung, Kang, & Al-Hussein, Mohamed (2020). "Virtual reality applications for the built environment: Research trends and opportunities." *Automation in Construction* 18(2): 103311.

Thank You