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VR-enabled Digital Twin System Architecture of User-centred Living Labs: A UX Study with Older Adults

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Abstract: This paper introduces the concept of Virtual Reality (VR)-enabled digital twin living labs, which are precise virtual replicas of real-world living labs, and explores their potential in housing research and development. The study outlines the system architecture of a VR-enabled digital twin living lab at the building scale, the Empathetic Home Digital Twin, and investigates the user experience of older adults engaging within this innovative system. The research employs a natural observation method to study the interactions, feedback, and implications for empathetic design. The findings highlight the importance of context familiarity, collective engagement, and intuitive design in building trust and promoting the acceptance of new technologies among older adult users. Key design recommendations, such as optimal VR session duration, gradual adaptation to the VR environment, concise orientation sessions, simplified interaction dynamics, seamless communication mechanisms, and an intuitive user interface, are provided for designing a VR experience tailored to engage older adults. The study acknowledges certain limitations, such as the need for more age-appropriate VR equipment and the small sample size of participants and suggests addressing these limitations in future studies. The potential of VR-enabled digital twins in housing research and development is significant, and future studies can explore their full potential to transform living lab approaches within housing research and development.

Keywords: VR-enabled digital twin; Living labs; User experience; Older adults; Empathetic design

1. Introduction

In recent years, living labs have emerged as a groundbreaking approach within the practice-oriented research ecosystem governing housing research and development. A living lab transcends conventional laboratory settings by integrating real-world contexts and user participation into the co-development and evaluation of innovations, technologies, products, or services (Følstad, 2008; Kareborn & Stahlbrost, 2009; Hossain et al., 2019). Despite the significant added value that living labs offer to current housing research and development, integrating innovative technologies into these real-world settings continues to present substantial challenges. These challenges include the complexity of system integration, leading to extended development cycles, the need for significant financial investments for the acquisition, installation, and maintenance of prototypes, and the considerable physical effort required for co-modifications and adjustments to

accommodate new configurations (Fehrer et al., 2024; Leal Filho et al., 2023; Ruijter & Meijer, 2020; Hossain et al., 2019). These challenges highlight the need for a more agile and modular approach in the co-development and deployment of innovations within living lab approaches.

Over the last five years, the evolution of Information and Communication Technology (ICT), Internet of Things (IoT), cloud computing, and immersive technologies has opened up unprecedented opportunities for adopting more flexible and modular frameworks within living labs. A notable innovation in this arena is the use of Virtual Reality (VR)-enabled digital twins (Jiang et al., 2021; Sepasgozar & Shirowzhan, 2024). A VR-enabled digital twin is a precise virtual replica of a real-world living lab. The use of a VR-enabled digital twin holds several promises, including: 1) the simulation of technological applications in a cost-effective and time-efficient manner, eliminating the need for physical alterations (Tagliabue et al., 2021; Molinari & Rolando, 2020; Lu et al., 2020; Argota Sánchez-Vaquero, 2022); 2) the rapid iteration and testing of Proof of Concepts (POCs) within a virtual environment, thereby reducing development cycles and physical exertion (Najafi et al., 2023; Bungay et al., 2021; Lu et al., 2020); and 3) the improved scalability and adaptability of POCs, thereby broadening the scope for experimentation and refinement without the financial and logistical constraints associated with conventional living labs (Jia et al., 2022; Zhang et al., 2022;). Today, VR-enabled digital twin living labs are being explored and utilized across various sectors, including energy transition (Opoku et al., 2024), agriculture (Majore & Majors, 2022), education systems (Tagliabue et al., 2021), and inclusive decision supports systems (Najafi et al., 2021).

While embedding such cutting-edge technologies into living labs can represent a pioneering contribution, it is imperative to note that success in living lab approaches is not measured by the sophistication of the technology, but by the harmonious orchestration of enriched experiences and meaningful human engagement that it facilitates. In other words, a system architecture at the intersection of smart-driven technologies, the cyber (physical and virtual) living environments, and meaningful and intuitive stakeholder involvement during the decision-making process is a prerequisite for a VR-enabled digital twin living lab approach. However, outlining such a system architecture is a key question that this paper aims to explore.

This study aims to outline the system architecture of a VR-enabled digital twin living lab at the building scale, namely the Empathetic Home Digital Twin. It then scrutinizes the experience of users (older adults aged 55+) engaging within these innovative systems, employing a natural observation method, and focusing on:

- I. Usability, and the perceived ease of use of such a system.
- II. Identifying and analysing key design elements and interactions that foster an empathetic user experience, showcasing the potential or challenges.
- III. Developing design recommendations to steer future innovations within the living lab research field.

Following this introduction, Section 2 details the system architecture employed in designing the VR-enabled digital twin living lab. Section 3 introduces the natural observation method and unveils the user experience study with older adults, concentrating on their interactions, feedback, and the subsequent implications for empathetic design. The discussion in Section 4 synthesizes insights from the user experience study, placing them within the wider scope of user-centred research. Section 5 encapsulates the study's key contributions and acknowledges its limitations for consideration in future research within the field of user-centred living labs.

2. Methods

2.1 Case study: Empathic Home living lab

“Empathic Home” is a user-centric living lab proposed by Mohammadi (2020) that seeks to merge physical infrastructure, such as homes, with technological advancements to create a living environment that intuitively responds to and anticipates the inhabitants' needs (Mohammadi, 2020). This living lab, with a three-story structure and a ground floor area of approximately 65 square meters, is situated within the IPKW industrial park in Arnhem, The Netherlands (Lieshout, 2023) (Figure 1, left). The Empathic Home venture has yielded effective POCs for implementing empathetic living environments. One such POC is the Guiding Environment, which supports independently living seniors with dementia with General Daily Activities (GDA), such as circadian rhythm, at their home environments (Grave, 2019). Within the Empathic Home living lab, these POCs often incorporate technological components, such as IoT sensor networks, intelligent user interfaces, and adaptable environmental controls to maintain and increase the autonomy of older adults in their living environment.



Living Lab Empathic Home



Digital Twin Empathic Home
(VR-enabled)

Figure 1. Empathic Home Living Lab and its digital counterpart.

2.2 System architecture

The system architecture of the VR-enabled Empathic Home employs a mixed-media prototyping approach. This method incorporates HCI devices, particularly VR, real-time data synchronisation between the Empathic Home's real-world structure and its virtual counterpart, and the home user (Figure). The principal components of the systems architecture are as follows:

- I. **Physical structure:** The physical component of the Empathic Home includes the building itself, outfitted with IoT sensors and actuators for environmental monitoring and control, such as temperature, humidity, lighting, and motion tracking. The physical components are integrated through a local cloud-based infrastructure, called “Home Assistant.” The Home Assistant is a smart home platform enabling residents of the Empathic Home living lab to automate, control, monitor, and enhance their comfort, security, and convenience.
- II. **Virtual Building Information Model (V-BIM):** The V-BIM of the Empathic Home is 3D modelled using Autodesk Revit, followed by enhancements in Unity, a game engine, for texturing, rendering, and data workflow exchange. This dual approach can leverage the strengths of both platforms to

create a dynamic digital twin environment, capable of interacting with the real-world Empathic home through cloud-computing computation.

- III. **Broker:** It creates a bidirectional communication flow between the real-world Empathic Home and its digital counterpart. The VR-enabled digital twin of Empathic Home broker encompasses five components:
- IV. **Cloud computing:** Provides the backbone for data storage, computational power, and analytics, facilitated through a dual-cloud architecture to meet both functional and computational demands.
- V. **Messaging protocol:** Implements Message Queuing Telemetry Transport (MQTT) for efficient and reliable communication among the IoT ecosystem, ensuring robust data exchange and system responsiveness.
- VI. **Automation:** Home Assistant serves as customisable platform for enabling the automation of smart devices. This platform receives messages, processed via the MQTT protocol from various IoT devices within the Empathic Home, and translate these messages into specific actions or adjustments to the home environment.
- VII. **Application Programming Interface (API):** This API facilitates the creation of dynamic and interactive virtual models that can mirror the physical state of the Empathic Home in real-time. Through MonoBehaviour scripts, the virtual Empathic Home dictates the behaviour of virtual objects, for examples, lights, within the Unity environment, enabling them to respond to user interactions, sensor data, and system commands. This interaction is not unidirectional; commands from the virtual environment can be translated back to physical actions within the home via the Home Assistant platform. The API thus supports a seamless interaction loop between the virtual and real-world Empathic Home, ensuring that changes in the digital twin can affect corresponding adjustments in the real-world environment.
- VIII. **VR interface:** Acts as the user interaction frontier to engage with the Empathic Home digital twin.
- IX. **Home user:** The stakeholders stand at the core of the system architecture, with their interactions via VR interfaces playing a key role in the digital twin of Empathic Home. The stakeholder can create a personalised and adaptive living environment that adjusts to their behaviours, preferences, and needs (Figure2).

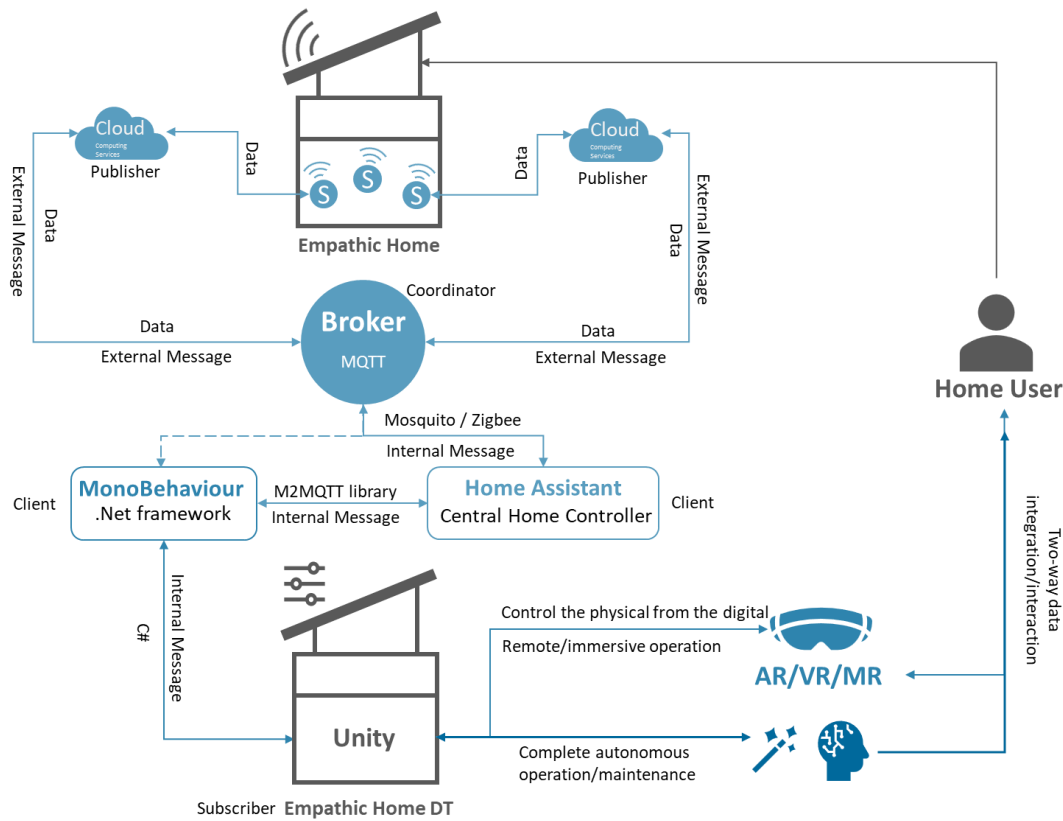


Figure 2. Conceptual system architecture of the VR-enabled digital twin of Empathic Home.

3. Results and analysis

3.1 User experience study

We adopted naturalistic observation methodology to scrutinise the user experience of the participants engaging with the VR-enabled digital twin of the Empathic Home living lab. This method was chosen to ensure the authenticity of interactions by observing participants in their natural environment, devoid of any experimental manipulation or interference (Angrosino, 2016). Our objective was to capture genuine user behaviours and reactions in real-world settings, thereby providing insights into the usability and effectiveness of a VR-enabled digital twin living lab for older participants.

A cohort of five participants (approximately 55 years old), with average postgraduate levels of education but no prior VR experience participated during the user experience study. They engaged with the digital twin model, which was also displayed on a 2D screen for observation by others. This setup facilitated an in-depth analysis of:

- I. **User initial perception:** Assessing the session setup for user convenience, engagement with the POCs, usability, ease-of-use for various functions (e.g., haptic feedback, hand gestures), user reactions to immersion, and overall satisfaction.
- II. **Design considerations:** Focusing on VR device features, session duration, environmental adaptation, interaction dynamics, data handling, and user interface design, aiming for insights to refine these aspects in future developments.

Our observations revealed significant insights into older adult's interactions and experiences, providing a foundation for enhancing VR-enabled digital twin models for this demographic.

4. Discussion

This study investigated the experiences of older adults interacting with a VR-enabled digital twin prototype, focusing on capturing their authentic behaviour and reactions within a natural setting to glean first-hand insights. The research findings have the potential to impact multiple disciplines, including ICTs, smart architectural technologies, and living labs by providing valuable insights on the development of methods and ICT technologies attuned to the needs of end users. Specifically, these insights are vital for developing interfaces and systems that accommodate the unique requirements and preferences of older adults, ensuring their inclusion in the evolving user-centric digital twins for living lab landscape. These insights are detailed below:

Insights from the experiment

A central finding of our investigation supports and expands upon the observations made by Merriman et al. (2016), who identified that engagement among older adult users is markedly improved in environments that are familiar to them (Merriman et al., 2016). The inference drawn is that integrating VR technologies into the BIM of the familiar settings like homes for older adults, and tailoring these technologies to their interests, can make VR seem less daunting and more accessible to them.

Further, our research advocates for a broader interpretation of 'familiar settings' to encompass not merely the VR environments themselves but also the social and cultural contexts that underpin both the experimental setup and the user experiences. This expansion appears important for building trust and promoting the acceptance of new technologies among older adult users. Specifically, our study highlights the following insights:

- I. **Familiarity with the experiment's environment:** Placing VR experiments in environments recognised by participants, such as communal areas within their living spaces, can enhance their trust in the experimental process, particularly for those encountering VR-enabled products for the first time. We underscore that the selection of familiar settings for conducting the experiment has a beneficial impact on enhancing older adult participants' confidence to facilitate their engagement in a more receptive manner.
- II. **Collective engagement:** Incorporating group dynamics into VR interventions has been demonstrated to boost participant engagement and confidence (Gomez et al., 2019). Our observations also indicate that enabling older adults to participate in groups, whether through forming cohorts with friends or neighbours, can foster a supportive environment that lessens reluctance towards technological interaction. This model of collective participation also seems promising for overcoming psychological barriers to VR technology adoption and increasing the experiment's effectiveness.
- III. **Communication strategy:** our findings is advocating HCI research for adaptable interaction modalities to accommodate user preferences and limitations. We observed that communicating in the participants' local language significantly ensures clear understanding and maintains engagement. The preference for verbal over written communication among senior participants necessitates provisions for oral interviews and the incorporation of auditory feedback mechanisms within the VR experience.

VR-enabled digital twin experience: design consideration for the senior users:

Our study also elucidates several factors that can be considered when designing VR experiences tailored to the needs of users:

- I. **Intuitive design and usability:** Our findings underscore the critical role of intuitive design – enabling the users to understand how to use the prototype without much effort. This principle is in concordance with the Technology Acceptance Model (TAM), which posits that the perceived ease of use is a significant criteria in the adoption of technology (Marangunić & Granić, 2015). We also recommend prioritising other criteria such as comfort, and safety when selecting VR headsets and related accessories. Specifically, it is advisable to choose headsets that are lightweight and adjustable, catering to diverse head sizes and visual requirements. Additionally, incorporating VR controls that demand minimal manual dexterity and ensuring auditory cues are clear and adaptable to various hearing abilities are essential consideration.
- II. **Session duration:** The cognitive and physical stamina of senior users should inform the optimal duration of VR sessions. Our findings suggest a maximum engagement threshold that avoids fatigue or discomfort, ideally not exceeding 20 minutes. This duration ensures that participants remain engaged and comfortable, without overwhelming them, thereby maximizing the benefits of the VR experience.
- III. **Adaptation:** Initial exposure to VR should emphasize comfort and gradual acclimatization to the virtual environment. While walking modes can offer benefits for immersion and wayfinding, seated navigation modes are recommended to ensure a comfortable and focused experience. This consideration is crucial in minimizing the risk of disorientation or discomfort among senior participants.
- IV. **Introduction to VR environment:** The entry process into the VR environment should be carefully managed, starting with an immersive setting that is familiar, pleasant, or calming. This should be followed by a concise orientation session to prepare participants for the experience. Such an approach facilitates a smooth transition into the virtual world, building participants' readiness and confidence.
- V. **Interaction dynamics:** The design should minimize the need for complex interactions that require significant input from the user, such as pressing buttons or using haptic feedback. In situations where user input is necessary, manual controls should be readily accessible to the experimenter to assist in navigating any difficulties. Simplifying interaction dynamics ensures that users can engage with the content without becoming overwhelmed by the technology.
- VI. **Communication/Instruction:** Communication from the experimenter to the participant during the VR session should be integrated within the VR environment whenever possible. Overlaying the experimenter's voice within the virtual setting, rather than having it come from the external world, helps maintain immersion and prevents confusion. This method supports a seamless experience, reinforcing the sense of presence within the virtual environment.
- VII. **Interface design:** The design of user interfaces and interaction mechanisms within VR must adhere to principles of simplicity, clarity, and accessibility. Features should include large, legible text, intuitive navigation paths, and high-contrast visual elements to accommodate visual impairments common among older adults. Such design principles ensure that the VR experience is not only accessible but also engaging for senior users.

5. Conclusion

In conclusion, the system architecture of the VR-enabled digital twin living presented in this paper can be considered a forward-thinking approach within the practice-oriented research ecosystem governing housing research and development. Furthermore, the user experience, particularly among older adults, investigated in this paper, can provide valuable insights into designing, implementing, and assessing the potential impact of such user-centric approaches within future inclusive decision-making systems.

Also, the findings of this study, including the context familiarity, collective engagement, and intuitive design, can be considered as driving factors for building trust and promoting the acceptance of new technologies among older adult users in future studies. Furthermore, key design recommendations, including an optimal VR session duration, gradual adaptation to the VR environment, concise orientation sessions to prepare participants for the experience, simplified interaction dynamics, seamless communication mechanisms, and an intuitive user interface, are driving factors when designing a VR experience tailored to engage older adults. Although VR-enabled digital twins offer significant potential for living lab approaches, this study acknowledges certain limitations. The current VR equipment used in the study may need to be more age-appropriate, leading to issues such as dizziness, fatigue, or disorientation during the experiment, particularly among participants with health issues. Additionally, the sample size of participants is small, which may affect the generalisation of the findings. Personal biases during the experiment due to natural observation behaviours may also affect the results.

To maximise the potential of VR-enabled digital twins in housing research and development, future studies should address these limitations and explore the potentials further. Building upon this research, future studies can harness the full potential of VR-enabled digital twins to transform living lab approaches within housing research and development.

References

- Grave, A. (2019). *Progress project: The Guiding Environment: The design of a guiding environment to stimulate older adults with early-stage dementia to enable them to live longer in their own homes.* Routledge.
- Argosino, M. V. (2016). *Naturalistic observation.* Routledge. https://books.google.com/books?hl=en&lr=&id=nKcYDQAAQBAJ&oi=fnd&pg=PT8&dq=naturalistic+observation+methodology+&ots=WSZvengsx0&sig=0sSjTGm3wvhtjiLqQwJbW_sBBTI
- Argota Sánchez-Vaquerizo, J. (2022). Getting real: The challenge of building and validating a large-scale digital twin of Barcelona's traffic with empirical data. *ISPRS International Journal of Geo-Information*, 11(1), 24.
- Bennett, J. W. (2017). *The ecological transition: Cultural anthropology and human adaptation.* Routledge.
- Bungay, H., Wilson, C., Dadswell, A., & Munn-Giddings, C. (2021). The role of collaborative working between the arts and care sectors in successfully delivering participatory arts activities for older people in residential care settings. *Scopus*. <https://doi.org/10.1111/hsc.13290>
- Dell'Era, C., & Landoni, P. (2014). Living Lab: A Methodology between User-Centred Design and Participatory Design. *Creativity and Innovation Management*, 23(2), 137–154. <https://doi.org/10.1111/caim.12061>
- Fehrer, J. A., Kemper, J. A., & Baker, J. J. (2024). Shaping Circular Service Ecosystems. *Journal of Service Research*, 27(1), 49–68. <https://doi.org/10.1177/10946705231188670>
- Følstad, A. (2008). Living labs for innovation and development of information and communication technology: A literature review. <https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2440026>
- Grave, A. (2019). *Progress project: The Guiding Environment: The design of a guiding environment to stimulate older adults with early-stage dementia to enable them to live longer in their own homes.* Routledge.

- https://www.hbo-kennisbank.nl/details/sharekit_han:oi:surfsharekit.nl:c656e15a-13c2-4beb-93bc-afa9bb02980f?q=anne&c=0&p=36
- Hossain, M., Leminen, S., & Westerlund, M. (2019). A systematic review of living lab literature. *Journal of Cleaner Production*, 213, 976–988.
- Jia, W., Wang, W., & Zhang, Z. (2022). From simple digital twin to complex digital twin Part I: A novel modeling method for multi-scale and multi-scenario digital twin. *Advanced Engineering Informatics*, 53, 101706.
- Jiang, Y., Yin, S., Li, K., Luo, H., & Kaynak, O. (2021). Industrial applications of digital twins. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 379(2207), 20200360. <https://doi.org/10.1098/rsta.2020.0360>
- Kareborn, B. B., & Stahlbrost, A. (2009). Living Lab: An open and citizen-centric approach for innovation. *International Journal of Innovation and Regional Development*, 1(4), 356. <https://doi.org/10.1504/IJIRD.2009.022727>
- Leal Filho, W., Ozuyar, P. G., Dinis, M. A. P., Azul, A. M., Alvarez, M. G., Da Silva Neiva, S., Salvia, A. L., Borsari, B., Danila, A., & Vasconcelos, C. R. (2023). Living labs in the context of the UN sustainable development goals: State of the art. *Sustainability Science*, 18(3), 1163–1179. <https://doi.org/10.1007/s11625-022-01240-w>
- Lieshout, T. van. (2023, January 23). Empathische Woning—DEEL Academy. <https://deelacademy.nl/empathische-woning/>
- Lu, Q., Parlikad, A. K., Woodall, P., Don Ranasinghe, G., Xie, X., Liang, Z., Konstantinou, E., Heaton, J., & Schooling, J. (2020). Developing a Digital Twin at Building and City Levels: Case Study of West Cambridge Campus. *Journal of Management in Engineering*, 36(3), 05020004. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000763](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000763)
- Majore, G., & Majors, I. (2022). Digital twin modelling for eco-cyber-physical systems: In the case of A smart agriculture living lab. *Proceedings of PoEM Forum*, 22, 98–112. <https://ceur-ws.org/Vol-3327/paper09.pdf>
- Marangunić, N., & Granić, A. (2015). Technology acceptance model: A literature review from 1986 to 2013. *Universal Access in the Information Society*, 14, 81–95.
- McDonagh, D., & Thomas, J. (2010). Disability + Relevant Design: Empathic Design Strategies Supporting More Effective New Product Design Outcomes. *The Design Journal*, 13(2), 180–198. <https://doi.org/10.2752/175470710X12735884220899>
- Merriman, N. A., Ondřej, J., Roudaia, E., O’Sullivan, C., & Newell, F. N. (2016). Familiar environments enhance object and spatial memory in both younger and older adults. *Experimental Brain Research*, 234(6), 1555–1574. <https://doi.org/10.1007/s00221-016-4557-0>
- Mohammadi, M. (2020). Empathic AI for Assisted Living: Experience Lab-Demo. <https://research.tue.nl/en/publications/empathic-ai-for-assisted-living-experience-lab-demo>
- Mohammadi, M. (2022). Shaping an empathic living environment: Design research as an incentive and medicine for healthy living. In *Applied Design Research* (pp. 207–216). CRC Press. <https://www.taylorfrancis.com/chapters/oa-edit/10.1201/9781003265924-19/shaping-empathic-living-environment-masi-mohammadi>
- Molinari, M., & Rolando, D. (2020). Digital twin of the Live-In Lab Testbed KTH: Development and calibration. International Conference Organised by IBPSA-Nordic, 13th–14th October 2020, OsloMet. BuildSIM-Nordic 2020. Selected Papers. <https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2683271>
- Najafi, P., Mohammadi, M., van Wesemael, P., & Le Blanc, P. M. (2023). A user-centred virtual city information model for inclusive community design: State-of-art. *Cities*, 134, 104203. <https://doi.org/10.1016/j.cities.2023.104203>
- Najafi, P., Mohammadi, M., Le Blanc, P. M., & Van Wesemael, P. (2021). Experimenting a Healthy Ageing Community in Immersive Virtual Reality Environment: The Case of World’s Longest-lived Populations. 2021 17th International Conference on Intelligent Environments (IE), 1–5. <https://doi.org/10.1109/IE51775.2021.9486595>

- Opoku, D.-G. J., Perera, S., Osei-Kyei, R., Rashidi, M., Bamdad, K., & Famakinwa, T. (2024). Digital twin for indoor condition monitoring in living labs: University library case study. *Automation in Construction*, 157, 105188.
- Ruijter, E., & Meijer, A. (2020). Open Government Data as an Innovation Process: Lessons from a Living Lab Experiment. *Public Performance & Management Review*, 43(3), 613–635. <https://doi.org/10.1080/15309576.2019.1568884>
- Sepasgozar, S., & Shirowzhan, S. (Eds.). (2024). *Digital Twin Adoption and BIM-GIS Implementation* (1st edition). Routledge.
- Tagliabue, L. C., Cecconi, F. R., Maltese, S., Rinaldi, S., Ciribini, A. L. C., & Flammini, A. (2021). Leveraging digital twin for sustainability assessment of an educational building. *Sustainability*, 13(2), 480.
- Warnke, P., Weber, M., & Leitner, K.-H. (2008). TRANSITION PATHWAYS TOWARDS USER-CENTRIC INNOVATION. *International Journal of Innovation Management*, 12(03), 489–510. <https://doi.org/10.1142/S136391960800200X>
- Zhang, H., Qi, Q., & Tao, F. (2022). A multi-scale modeling method for digital twin shop-floor. *Journal of Manufacturing Systems*, 62, 417–428.