New Design Ideas
Vol.8 | Special Issue | ICCAUA2024, pp.24-58
https://doi.org/10.62476/ndisi.24

TRANSFORMING ARCHITECTURE IN THE POST-DIGITAL ERA: LEVERAGING ACTOR NETWORK THEORY AND SPATIAL AGENCY FOR INTERACTIVE SPACES

Fatah Bakour*, Ali Chougui

Institute of Architecture and Earth Sciences, Housing and Environment Laboratory, Ferhat Abbas University, Setif, Algeria

Abstract. The rapid advancement of cutting-edge technologies, such as virtual and augmented reality, is significantly influencing the transformation of the built environment. It has evolved from a static backdrop of activities to an active participant, creating an interactive space that responds to user actions spatial components and environmental data. This transformation has led to the emergence of a socio-technical network where all elements contribute to the interactive environment. Key to this evolution is the spatial agency as a reactive approach that revolutionizes the conceptualization of the built environment. By fostering innovation and improving the quality of relationships between human and non-human elements within dynamic socio-technical networks, this approach has garnered attention in recent studies aiming to redefine interactive spaces through the agency concept. In particular, Actor-network theory (ANT) has been adopted as a methodological and ontological tool to address this paradigm shift. However, there remains a lack of comprehensive representation and practical application of (ANT) in addressing the complexity of spatial agency within the design process of interactive spaces. To bridge this gap, this study explores the potential of (ANT) in illuminating the spatial agency process within interactive spaces, with a particular emphasis on the agency of technological objects. Through an examination of the "Spatially Intelligent Arts Center", this research utilizes ANT's translation process via the Mapping Controversies technique to visually represent and analyze the agency of technological objects. The study's findings underscore the significant role of ANT's translation process in highlighting the agency of technological objects, including sensory interactions, augmented reality applications, memory lane and interactive projections, all of which enable continuous system development and real-time assessment. This exploration provides architects with a framework to analyze and steer the design of culturally intelligent spaces through the lens of the spatial agency approach.

Keywords: *Interactive spaces, (ANT), spatial agency, technological objects, mapping controversies.*

*****Corresponding Author:*** *Fatah Bakour, Institute of Architecture and Earth Sciences, Housing and Environment Laboratory, Ferhat Abbas University, Setif, Algeria, Tel.: +21363304171,*
e-mail: fatah.bakour@univ-setif.dz

Received: *23 May 2024;* ***Accepted:*** *18 August 2024;* ***Published:*** *10 October 2024.*

1. Introduction

The rapid advancement of technology is reshaping every aspect of society (Guney, 2018). In the field of architecture, this progress has given rise to innovative concepts, practical designs and creative visual elements (Al-Saigh & Mahmoud, 2023). The focus is on creating environments that support both cognitive and physical health, providing access to smart, interactive spaces tailored to individual needs (Knox, 2021; Boychenko, 2019). Spatial technologies offer increased flexibility and adaptability, allowing the built

How to cite (APA):
Bakour, F., Chougui, A. (2024). Transforming architecture in the post-digital era: Leveraging actor network theory and spatial agency for interactive spaces. *New Design Ideas, 8*(Special Issue), 24-58 https://doi.org/10.62476/ndisi.24

environment to actively engage with human activities (Gaha, 2023). Similarly, digital technologies have blurred the lines between virtual and physical worlds, enabling continuous interactions within the realm of interactive architecture (Amini *et al*., 2019; Haque & Somlai-Fischer, 2005; Jaskiewicz, 2013). As a result of this technological progress, the design process for interactive spaces now emphasizes the mechanical behavior of the environment, user requirements and internal and external conditions, rather than focusing solely on the final product (Amini *et al*., 2019).

Moreover, the design of interactive spaces incorporates social factors and enables structural adjustments based on user preferences (Boychenko, 2019). This fluid process encompasses a complex socio-technical network that connects different stakeholders and involves diverse power dynamics and interactions among human and non-human elements, including technology and space. At the core of this process is the spatial agency approach, which aims to offer a distinct ontological framework for understanding and highlighting this interactive design process.

Therefore, The spatial agency approach is deeply rooted in Henri Lefebvre's "spatial triad" model (Henri & Donald, 1991), delving into the diverse categories and characteristics of space, their dynamics and interconnections. It encourages a dynamic process of challenging conventional architectural practices by emphasizing temporary socio-technical networks based on the specific distribution of power and synergy among participants. This approach significantly impacts how we perceive and shape the built environment (Sadri, 2018; Awan *et al*., 2013), focusing on the process rather than solely the architectural outcome (https://www.spatialagency.net/).

Recently, a number of studies have aimed to present a new way of understanding and exploring interactive spaces by using the concept of agency within the framework of Actor-Network Theory (ANT). This theory originated in the field of science and technology studies (Callon, 1986) and was further developed by (Law, 1986) and (Latour, 1988). It provides an ontological framework for understanding and examining the interaction and connection between space and agency within the interactive spaces system.

Consequently, there is a significant gap in the literature regarding the lack of comprehensive representation and practical application of Actor-Network Theory (ANT) to highlight how the spatial agency process is shaped and performed by technological objects in interactive space systems. This gap hinders the ability to fully understand and leverage the dynamic interactions among various human and non-human actors (technological objects) that shape interactive space systems. Addressing this issue is crucial for advancing the design and construction of adaptive, responsive environments in the post-digital age.

Accordingly, this study addresses how Actor-Network Theory (ANT) as an ontological tool allows us to open the "black box" and decode the dynamics of the spatial agency process in interactive spaces to highlight the agency of technological objects within its socio-technical network?. Consequently, this research question leads to the following hypothesis: The agency of technological objects such as (AR) and (VR) within interactive space systems significantly influences the socio-technical network and overall performance of these environments, by employing the translation process of Actor-Network Theory (ANT) through the Mapping Controversies method, we can gain a detailed understanding of these dynamics, which will provide architects with practical insights and an ontological framework to analyze and design more adaptive, responsive and intelligent spaces.

This research seeks to open the black box of the spatial agency process and ontologically trace, visualize and analyze the characteristics and association quality of key actants that influence the network of interactive spaces, emphasizing the role of technological objects within this dynamic network, with a specific focus on culturally intelligent spaces.

The primary contribution of this research lies in its innovative application of Actor-Network Theory (ANT) at the intersection of the spatial agency approach and interactive spaces design process. It presents a referential strategy based on the translation process of (ANT) as an ontological framework for architects to analyze culturally intelligent spaces and as a strategic guide to designing culturally intelligent spaces. By offering a comprehensive understanding of the spatial agency process, this research provides architects with the knowledge to create more adaptive and responsive built environments, providing a new perspective on the dynamic interactions among human and non-human actors within these environments. Although (ANT) has been widely used in science and technology studies (STS), its application to spatial agency in architecture has been limited.

This study utilizes both qualitative and quantitative methods to construct a new framework for systematically identifying, visualizing and analyzing the agency of technological objects within culturally intelligent spaces. To accomplish this, the research applies the Mapping Controversies technique as a practical tool to Bruno Latour's Actor-Network Theory (ANT) (Venturini, 2010). This approach aids in understanding and clarifying the relationships between human and technological entities in interactive space systems.

The subsequent sections of this article are organized to provide a comprehensive overview and contribute to the understanding of how the spatial agency approach shapes and deals with interactive spaces. We will also introduce the development of a unique methodology to identify, visualize, analyze and represent the highly dynamic and multidisciplinary aspects of the subject under study. This document is divided into four parts. The first chapter reviews the state of play on technological advancement and the emergence of interactive spaces and presents a theoretical background related to the literature review of the spatial agency approach in architectural practice. It also provides an overview of the investigation of the concept of agency in interactive spaces and conceptualizes the relationship between Actor-network theory and the spatial agency approach. Additionally, it provides a debate of related previous studies and highlights the importance of the Mapping controversies technique. The second chapter presents the procedural steps of the proposed methodology based on the Mapping controversies method. The third chapter presents a relevant case study selected from the literature, which is a recent experience of a pioneering government-funded applied research project of a “culturally intelligent place” called the ‘Spatially Intelligent Arts Centre’. The fourth chapter presents the results, discusses the main contributions of this paper and gives important recommendations to enhance the understanding of the spatial agency approach in interactive spaces. It ends with a conclusion that offers additional insights, including prospects for future research. The structure of this research can be summarized in Figure 1 as follows:

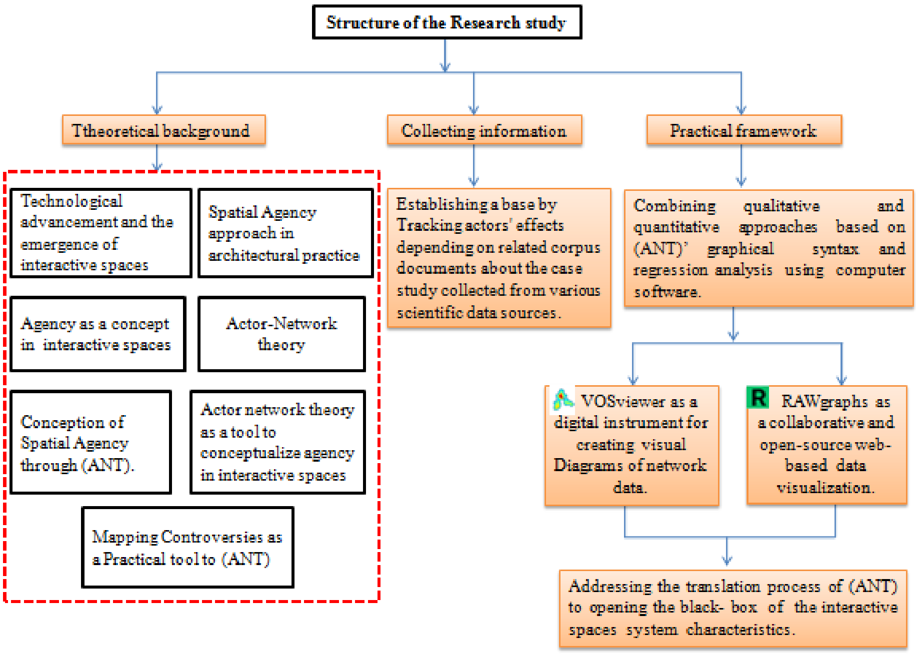

Figure 1. Structure of the Study
Source: Developed by Author

2. Literature Review

In this section, we aim to provide an overview of the diverse research approaches in human-building interaction (HBI) to position our research within the broader context of intelligent space creation. Following this, we will delve into the concept of "spatial agency" and establish a strong theoretical framework by thoroughly examining relevant literature. This section is structured to address the theoretical inquiries and considerations of our study by emphasizing alternative conceptualizations of interactive spaces in the post-digital age through the lens of the agency's concept. We will also reference prior studies related to our research to highlight the research gap, focusing particularly on exploring Actor-Network Theory (ANT) within the spatial agency approach in interactive spaces. Additionally, we will provide a theoretical overview of the Mapping Controversies technique as a practical tool for Actor-Network Theory (ANT) to aid in the conceptualization and interpretation of the spatial agency approach. Building on this, we aim to categorize and identify the sources of empirical materials used to examine the system of interactive spaces and its socio-technical dynamic network in the post-digital age, with a specific focus on the agencies of technological objects.

2.1. Technological advancement and the emergence of interactive spaces

The integration of technology into architecture and the built environment has led to two primary approaches. The first approach focuses on incorporating advanced technologies and systems to enhance building design, construction and maintenance processes. This approach aims to improve efficiency and functionality, as described by (Ahmadi-Karvigh *et al.*, 2017). The second approach to human-building interaction (HBI) emerged with the transition to Industry (4.0) and focuses on improving interactions between users and the built environment. This approach involves embedding information into the physical environment to create innovative spatial, physical and social experiences for building users, as described by (Kocaturk *et al*., 2024). This current approach aims to facilitate the development of seamless sensing and actuation capabilities, enabling the creation of data pathways that respond to users' activities, as highlighted by the study of (Nabil & Kirk, 2019).

Therefore, this approach will be the primary focus of this study, as illustrated in Figure 2. In contrast, Wiener initially introduced the concept of "interactivity" in his book "*The Human Use of Human Beings*" In this influential work, he defined interactivity as the concept of reactions and a method of controlling the system, thereby laying the foundation for the creation of interactive spaces.

Likewise, Weiser (1995) introduced the concept of "*Computation Everywhere*" which had a significant impact on the development of interactive environments driven by computer technology. This trend is expected to result in the creation of seamless sensing and actuation capabilities, enabling the generation of responsive data pathways based on users' activities. Building on this idea Tyson (2023) proposes the concept of an 'intelligent place' as more than just a structure equipped with technology. It integrates design, user experience, functional efficiency and performance intelligence to promote meaningful human interactions and arrangements. Similarly, Boychenko (2019) defines emerging spaces as dynamic and time-based, indicating a significant shift from static and fixed spaces. She argues that built space features and users can be seen as actors or small particles within a unified network. They are constantly sensing each other and changing, all working towards a common goal and displaying swarm behavior.

On the other hand, the process of creating digital interactive spaces encompasses various features, including the integration of visual and sensory elements such as color, light and texture through the use of intelligent materials, this integration improves perceptual knowledge, confusing architectural boundaries and maximizing functional potential (Al-Saigh & Mahmoud, 2023). Accordingly, Living Surface demonstrates advanced technology by adjusting its physical form based on user physiological data collected by sensors, This interactive surface offers both visual and tactile feedback and displays images like an oriental carpet or artwork by an international artist, also it recognizes users' fingerprints, enabling dynamic transformations and enhancing the interactive experience (Yu *et al*., 2016). Similarly, this technology has the potential to be used for real-time data sharing and recreation in public spaces, aimed at enhancing user satisfaction and engagement (Al-Saigh & Mahmoud, 2023).

As well as, The integration of game engines with Building Information Modeling (BIM), Virtual Reality (VR) and Augmented Reality (AR) applications is currently being developed to streamline design processes and enhance collaboration among building project stakeholders. (VR) and (AR) can be integrated across multiple platforms and databases, making them suitable for use in all stages of building development (Panya *et al*., 2023).

2.1. Spatial Agency approach in architectural practice

According to Giddens (1984), "agency" refers to human action within the framework of the rules and regulations present in social systems. These systems both empower and constrain individuals, positioning them as agents of change within a dynamic social space. The concept of spatial agency delves into the interconnectedness of architectural resources, processes and elements, including both human and non-human aspects, with agency, emphasizing that they are not separate from architecture and space

(Lorne, 2017). This approach requires a broader theoretical framework that considers non-human elements in addition to human-centered action (Awan *et al*., 2013).

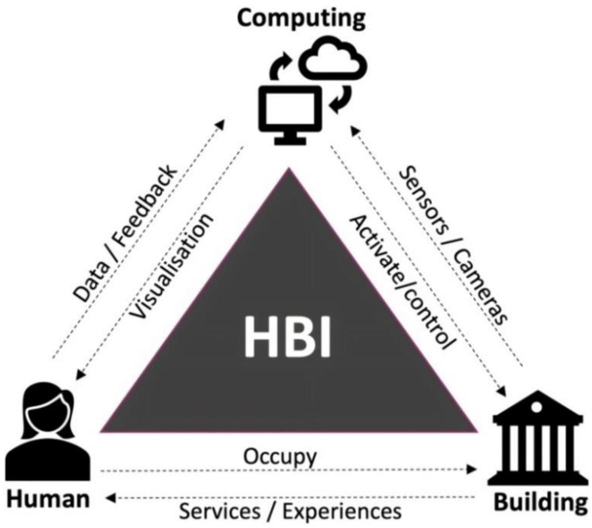

Figure 2. (HBI) as an interplay between people, building and computing
Source: Kocaturk et al. (2024)

In the same vein, the Spatial Agency approach is rooted in Lefebvre's ideas (Strickland, 2014). It highlights that architects do not work in isolation when shaping space; rather, they take into account the social and material elements of space and how they impact the actions and behaviors of both creators and occupants. Lefebvre's theory (2014) underscores that space is a social construct shaped by and shaping systems of production, class consciousness and everyday life.

Lefebvre (2014) proposes that the formation of space is shaped by the interplay of abstract and concrete elements, including social (lived) space. This interplay involves the tensions arising from conflicting forces within spatial organization. Furthermore, the concept of spatial agency advocates for collaborative approaches that extend design practices beyond the scope of individual clients (https://www.spatialagency.net/). In the book "*Other Ways of Doing Architecture"* the concept of Spatial Agency delves into the potential for design intelligence to be harnessed in an inclusive and politically progressive manner, all the while acknowledging the expertise of architects. It emphasizes the significance of "spatial judgment, shared knowledge and critical consciousness" (Awan *et al*., 2013). The aim is to foster design approaches that prioritize society by engaging with a diverse range of human and non-human participants, thus creating opportunities that challenge prevailing norms (Lorne, 2017). Schneider and Till (2009) consider spatial agency as a framework that involves sharing power and enabling others to partake in decision-making processes in a participatory and proactive manner. Rather than simply transferring decision-making authority from the dominant sectors to the previously marginalized, it involves empowering others to assume control and instigate alternative spatial processes. Additionally, Sadri (2018) defines Spatial Agency as a contemporary and critical deconstructive approach geared toward reshaping the practice of architecture.

Thus, The concept of spatial agency is rooted in a dynamic and evolving process that engages various stakeholders in complex socio-technical networks, It emphasizes the importance of comprehending agency beyond human intentionality and architecture beyond materiality (https://www.spatialagency.net/). To fully understand spatial agency, it's essential to broaden our perception of agency to include deliberate actions such as design and planning, as well as other ways in which individuals or groups can shape and influence the physical environment (Hammond, 2018).

2.2. Agency as a concept in interactive spaces

Numerous studies in the literature have delved into the concept of agency, underscoring the significance of comprehending and navigating the intricacies of interactive architecture. The perspective of viewing interactive spaces as a system of agencies necessitates the establishment and cultivation of effective networks for agency components, whether they are actors/actants or networks. Therefore, it is paramount to consider the terminology and processes of spatial agency as a strategy for contemplating, examining and enhancing the unique features of the constructed environment in the post-digital era and ensuring its sustainability. Several specialized studies have articulated the concept of spatial agency as an alternative approach to managing interactive architecture. Boychnko's research delves into the exploration of spatial agency within interactive environments. It defines interaction as the dynamic interconnected system formed by individuals and architectural components within a specific area, where both humans and non-human entities exert influence. This structure facilitates direct communication between the two (Boychenko, 2017). In the context of interactive space behavior, agency is often described as the notion of synergy and user empowerment. Similarly, the concept of spatial agency can be approached from a cybernetic perspective, elucidating the fundamental relationship between interactive space and user agency (Boychenko, 2019).

Likewise, the study by Frazer (1993) provides an overview of Pask's perspectives as a prominent figure in second-generation cybernetics, emphasizing the incorporation of feedback into systems design and component specification in spatial design. By employing intelligent systems, interactive spaces have the potential to evolve into actively engaging environments by involving users as participants in a larger control loop. According to Pask's in (Frazer, 1993) study the final product no longer depends solely on the designer as the ultimate authority instead, users should have the power to play a substantial role in shaping their environment with adaptability. Furthermore, Haque (2007) referenced Pask's approach to architecture as the creation of tools that individuals can use to shape their surroundings and in turn, develop their sense of control. As well as, authors such as Negroponte (1975) extensively defined interactive architecture or computing-enabled environments, as focusing on liberating the user from the authoritarian role of the architect by offering autonomy and adaptability.

2.3. Actor-Network theory: An overview

Actor-Network Theory (ANT) emerged as part of the broader field of Science and Technology Studies (STS). This area of study sought to influence social and scientific inquiries into the construction of scientific truths and technological artifacts, enabling the concurrent examination of social and spatial influences (Latour, 1987; Law, 2008). These studies emphasized that facts are not the result of logic but of the logistics through which they are recorded, organized and disseminated (Blok & Jensen, 2019). Therefore, the (ANT) approach challenges the modernist separation of nature and society and proposes a sociology of circulation. (ANT) focuses on the process of assembling the world through the connections between human and non-human actors. To us, (ANT) is not just a theory making universal claims but primarily a methodology that offers an analytical framework based on the notion of not dividing the natural from the social. This notion stems from the principles of relationality, symmetry and association (Farìas & Bender, 2012).

Actor-Network Theory (ANT) views the world as a series of interconnected networks, highlighting agency, the performative aspects of actors and the influence of both human and non-human entities. (ANT) represents an ontological approach that enables ongoing socio-technical relationships, treating concepts such as power or agency as enacted rather than fixed territories subject to examination at micro- or macro-levels (Latour, 1999). The (ANT) forms an extensive web of interactions without a clear beginning or end point (Fenwick & Edwards, 2010). Actor-network theory (ANT) does not assert universal claims; rather, it provides an analytical framework based on the concept of not separating the natural from the social. This idea revolves around the principles of relationality, symmetry and association (Farìas & Bender, 2012).

Hence, the principle of relationality encompasses both material and semiotic elements to establish their connections, configurations and influences. Action is understood as interaction and transformation, while the principle of symmetry dictates that both human and non-human entities should receive equal attention when examining social dynamics. This framework is applicable to all entities. The notion of association underscores the interconnectedness of humans and non-humans within actor networks, even including entities that are not naturally social. The equal interchange between humans and non-humans presents an analytical perspective (Law, 1992).

In addition, Actor-Network Theory (ANT) serves primarily as a methodology that offers “some infra-language to support [sociologists of circulations] in being attentive to the actors' own fully developed meta-language” (Latour, 2007). Part of this infra-language revolves around the concept of translation, which is employed to study the process of establishing equivalents that facilitate the connection, definition and organization of elements (Callon, 1986). Translation enables us to describe how networks are formed, negotiated and stabilized. A more detailed examination of the translation process within (ANT) and its foundational concepts will be presented in the methodological section of this study.

2.4. Conception of spatial agency through Actor-Network theory

The idea of spatial agency encounters its foundation in the dichotomies of subject/object, human/non-human and material/non-material, as well as in the confines placed by the theoretical and methodological traditions of social research (Latour, 1996). Latour's (2007) work “*Reassembling the Social”* introduces the actor-network theory (ANT) to clear light on the theoretical and methodological limitations of traditional social theory, differentiating between the sociology of social and the sociology of associations. He offers a novel sociological concept, the “sociology of translation”, aimed at tracing associations. (ANT), as a theoretical framework within the “sociology of associations”, offers an understanding of agency that integrates the human and the non-human via the concepts of actor/actant and “actor-network”. It challenges static conceptions of architecture by dynamically redefining it to consider the associations between humans and non-humans. While the complexities of Latour's (ANT) project lie beyond the scope of this document, we will explore key concepts such as “Actor/Actant”, the “*Actor-network”*, the “*translation process*” and the concept of “*Black box*” to present an alternative theoretical framework for conceptualizing spatial agency, shifting out from the human-centered approach of “social sociology”.

2.5. Actor network theory as a tool to conceptualize agency in interactive spaces

In this part, we undertake a critical examination of previous research at the intersection of agency, interactive spaces and Actor-Network Theory (ANT). By shedding light on methodological limitations and inconsistencies in prior studies, despite that these previous study are very few, we aim to demonstrate how our methodology fills these gaps.

1 - The study by (Boychenko, 2019) examines the socio-technological relationships in interactive architecture, employing (ANT) to reveal the complexities of these interactions. It treats human and non-human actors with equal agency. Although the evidence of this studyit largely theoretical, offering limited empirical evidence and practical applications.

2 - Study by (Boychenko, 2020) this paper applies (ANT) as a methodological tool to understand the role of interactive space in social relationships. The study treats interactive space as an active participant in social relationships, considering it an actor within a heterogeneous network of human and non-human components. A full-scale interactive prototype was used to test and analyze various ways of real-time communication between visitors and the space, assessing their responsiveness to different types of signals (light, sound, motion) and how participants behave. This methodology focuses on real-time interactions without a comprehensive analysis of the broader socio-technical network. The study emphasizes immediate responses to stimuli but lacks a deeper exploration of how these interactions evolve over time and influence the overall network dynamics.

3 - The study by (Boychenko, 2021) redefines the role of interactive architecture in social relationships, emphasizing bi-directional communication and treating architectural components and users as participants of a socio-technical network. Although the study used (ANT) to highlight the agency of interactive spaces, it does not deeply investigate the specific contributions of technological objects within these interactions.

4 - Study by (Knox, 2021) This research defines the communicative performance of interactive spaces using ANT, focusing on non-verbal signals (light, sound, motion) and their impact on human behavior. This study focuses on communicative performance but does not explore the ontological implications of these interactions within the broader socio-technical network.

5 - The study by (Boychenko *et al*., 2022) uses (ANT) to define the role of interactive space in social relationships, treating interactive space as an actor within a heterogeneous network of human and non-human components. A full-scale interactive prototype was employed to analyze real-time communication and human responsiveness to various signals. Accordingly, While the study successfully demonstrates the application of (ANT) to analyze interactive spaces, it focuses primarily on real-time human responses to non-verbal signals without exploring the deeper complexities and dynamics of the socio-technical network.

Despite the valuable insights provided by these previous studies, there is a lack of comprehensive network analysis. Prior studies often focus on specific interactions without mapping the entire socio-technical network, leading to an incomplete understanding of the spatial agency approach. Additionally, there is an absence of a robust ontological framework (ANT), resulting in previous research lacking a comprehensive practical model to analyze the interactions between humans and technological objects in these interactive spaces.

2.6. Mapping Controversies as a practical tool to Actor-Network Theory (ANT)

The Controversy Analysis, also referred to as the Mapping Controversy technique, is a powerful tool utilized in social science research. It enables researchers to investigate contentious topics by employing diverse methods to visualize and analyze the issues (Venturini, 2012). Developed by Latour, this approach incorporates actor-network theory (ANT) as an instructional tool, preserving the core concept of (ANT) while simplifying the method's complexity for researchers (Stark, 2001). With the assistance of advanced network analysis tools, the analysis of controversies has become increasingly diverse, leveraging digital technologies to capture, analyze and visualize data. This often involves the utilization of big data and the internet, offering relevant context. By visualizing the network, any controversies are brought to the forefront, laying the groundwork for meaningful discussions (Marres, 2015). According to Latour (2017), a “network” is not a physical entity but a documentation of an object's trajectory. It traces, describes, files, lists, records, marks or tags a trajectory. This visualization of the network highlights any controversies, prompting meaningful discussions. This method provides descriptions of architectural objects, practices and processes and explores alternative approaches to analyzing digital data to depict space as a perpetually moving network where controversy is prevalent (Cheng & Neisch, 2023).

3. Material and Methods

3.1. Criteria for selecting the case and analysis methods

This study’s case selection criteria are based on various considerations: related to the fundamental theoretical conception of Spatial agency and (ANT), these criteria aim at deconstructing the heterogeneous network of interactive space systems and identifying the key actors in the new connection rebuilt by technological objects. These criteria are defined as follows:

Relevance to Research Objectives: The 'Spatially Intelligent Arts Center' project directly addresses the transformation of static spaces into dynamic, interactive environments. This aligns with our objective to explore the application of Actor-Network Theory (ANT) in the context of spatial agency and technological objects within interactive spaces.

Interdisciplinary and transdisciplinary Collaboration: The project transcends conventional boundaries by merging the expertise of architects, computer scientists, researchers from the university, user experience designers, spatial computing specialists, technology developers and interface designers. This collaboration is crucial for a holistic understanding and application of (ANT) in spatial intelligence, demonstrating the integration of diverse expertise.

Design-Thinking Methodology: Adopting a design-thinking methodology, the project challenges conventional architectural design limitations and offers a tangible illustration of human-building interaction research and practice. This approach is essential for examining the dynamic interactions and the agency of technological objects within the space.

Practical Implementation and Testing: The project's focus on research, ideation, design, development and testing of scaled prototype applications within an actual Arts Center building provides a practical and empirical foundation for the study. This real-world application is vital for understanding the dynamic interactions and operational efficiency of the space.

Technological Innovation: Emphasizing technological innovation, the project integrates (AR) and real-time sensing to create new user experiences and optimize operational efficiency. This innovation is critical for demonstrating the potential of (ANT) to analyze and enhance interactive spaces.

Human-Building Interaction: The project delves into how responsive interfaces affect human-building interactions, continuously altering the information on displays in real time. This interaction serves as an illustrative instance of dynamic and responsive rapport between individuals and architectural spaces, highlighting the project's significance as a model for human-building interaction in cultural buildings.

Socio-Technical Network and Agency: The “Spatially Intelligent Arts Center” exemplifies a complex socio-technical network where human actors (users, designers, architects) interact with non-human actors (technological objects, interfaces, sensors). Each actor in this network possesses agency, actively influencing and being influenced by the interactions within the space. This dynamic interplay of actors aligns with (ANT) principles, showcasing how technological objects and human users co-create the responsive environment. By mapping these interactions, the project reveals the critical role of technological objects in shaping user experiences and operational efficiency, providing valuable insights into the functioning of socio-technical networks in interactive spaces.

Relation to Spatial Agency approach: The 'Spatially Intelligent Arts Center' project exemplifies spatial agency by transforming an existing arts center into a dynamic, intelligent environment. It demonstrates how architectural spaces can become active participants in shaping user experiences through continuous interaction and feedback. By integrating real-time data from sensors and user interactions, the project shows how spaces can adapt and respond to changing conditions and needs. This adaptive quality underscores the concept of spatial agency, where the built environment is not merely a backdrop but an active agent influencing and being influenced by the socio-technical network of actors within it.

3.2. Data collection steps, simpling and sources

The research data was collected to address a specific simpling a particular category of interactive spaces which is culturally intelligent spaces. using a qualitative approach and analyzed with “text mining analysis” in the “VOSviewer” software (Van Eck & Waltman, 2011). This method enabled us to examine the interactions among actors based on their occurrence in the text and to generate a network map using various graph optimization algorithms. By studying the co-occurrence of actors in the text and the strength of their connections, we could determine their importance and position in the network. The data collection process of the final sample included a diverse range of documents collected through three main steps. Initially, we gathered relevant documents and texts from various scientific sources and media such as “Google Scholar”; “Deakin University Research Repository”; “social media” and relevant websites using the Mapping Controversies technique (Yaneva, 2016). After compiling and annotating these documents into a single text-based file, we proceeded with the data cleaning and formatting to prepare the file for input into the “VOSviewer” software. Finally, we utilized the natural language processing algorithms in the “VOSviewer” software to automatically analyze and code the underlying network of actors. Additionally, Ethical considerations in this study are addressed by ensuring the data collection process respects privacy, confidentiality and proper consent.

3.3. The approach: The (ANT) translation process application

The Actor-Network Theory (ANT) investigation involves an in-depth examination that provides detailed explanations of the human and non-human elements involved (Mclean & Hassard, 2004). This comprehensive approach aims to understand how these elements interact within the network and identifies the key actors needed to form connections. In innovation studies, the concept of translation in actor-network theory (ANT) is widely recognized as a fundamental aspect that influences the formation and dynamics of networks. It helps to explain the processes of network establishment, growth, participant integration and the achievement of temporary stability (Cresswell *et al*., 2010; Strong & Letch, 2013).

Accordingly, Callon (1986) outlines four distinct phases in the process of "translation", which are further explained in subsequent discussions. The initial phase, *Problematization*, involves defining problems, refining actors' identities, their association with the issue, their essential roles, the involvement of non-human actors and the emergence of a central actor. Subsequently, *interessement* occurs, in which an actor or a group of actors claim and validate the identities of other actors through actions that involve all parties. *Enrolment*, if *interestment* prevails, involves assigning interconnected roles to consenting actors. Finally, *mobilization* involves reaching agreements on spokesperson roles or representations. As a result, translation enables the formation of consensus and alliances (Callon, 1986). While acknowledging the limitations of this paper, for interested readers, a comprehensive explanation of (ANT) concepts and methodology is recommended in (Latour, 2007). Although the abstract nature of the concepts is acknowledged, it is believed that they are sufficiently clear to address the study at hand.

3.4. The procedural workflow steps of the proposed Method

In our analysis, we employed a three-phase procedural approach to systematically deconstruct controversies and effectively apply the four moments of the translation process of Actor-network theory (ANT) by Bruno Latour (Callon, 1984).

This approach, anchored in Mapping controversies, enables us to develop analysis diagrams that illustrate a socio-material perspective, mapping the interactions between humans and technological elements. To deconstruct controversies, we utilized precision digital tools featuring various graph types and optimization algorithms. Specifically, we utilized "VOSviewer 1.6.20" to explore and analyze scientific data networks (https://www.vosviewer.com/) and "RAWgraphs", an open-source data visualization tool for complex data (Mauri *et al*., 2017) This strategy allowed us to apply the four moments of the translation process of (ANT) effectively.

The initial stage involves identifying and tracing the impact of actors throughout the transition process. This stage is essential as it enables the data to be coded in the software, based on the collection of various relevant data related to the case study. We create co-occurrence networks of the most relevant items using natural language processing algorithms in the "VOSviewer" software (Van Eck & Waltman, 2011).

This stage aligns with the moment of *Problematization* in the translation process of (ANT).

In the second stage, we employed various visualization techniques to map and display the network layout of the actants. This included using the total link strength between actors as weight and the co-occurrence of actors as weight. Visualization methods such as network visualization and network density visualization of items (Van Eck & Waltman, 2014), which are based on the Force-Directed algorithm (Waltman & Van Eck, 2013), were utilized. This stage mirrors the moment of *interssement* within the translation process of (ANT), allowing us to visualize the intermediary actors within the network. Furthermore, this stage aids in conceptualizing and visualizing the obligatory passage point (OPP) actor and the focal actor within our network structure, which we will discuss as a set of key actors in the translation process of (ANT) in the results section of this paper.

In the third stage, we utilized cluster density visualization to identify the subsystems within our network interactive space network that define our selected case study. These subsystems refer to groups or clusters of actants that share common attributes, with each cluster represented by a specific color range. The detection of these clusters is based on a modularity-based community detection algorithm using the software “VOSviewer 1.6.20”. This stage is analogous to two successive moments which are the *Enrolment* moment and the *Mobilization* moment of the (ANT) translation process, in this stage, we also performed a regression analysis using a computational method based on graph algorithms in the “RAWGraphs” tool (Mauri *et al*., 2017) to identify the relationships between the actors involved in the network structure and to determine the key actants that shape the dynamic network and their alignment with the related key actors within the translation process of (ANT) (Walsh & Renaud, 2010), including mediators, boundary objects and spokespersons. These key actors will be thoroughly discussed in the results section. Additionally, we highlighted the agency of the most influential cluster within our network structure. This allowed us to gain insight into the agency of technological objects within the network. The procedural steps of the methodology are summarized in Figure 3.

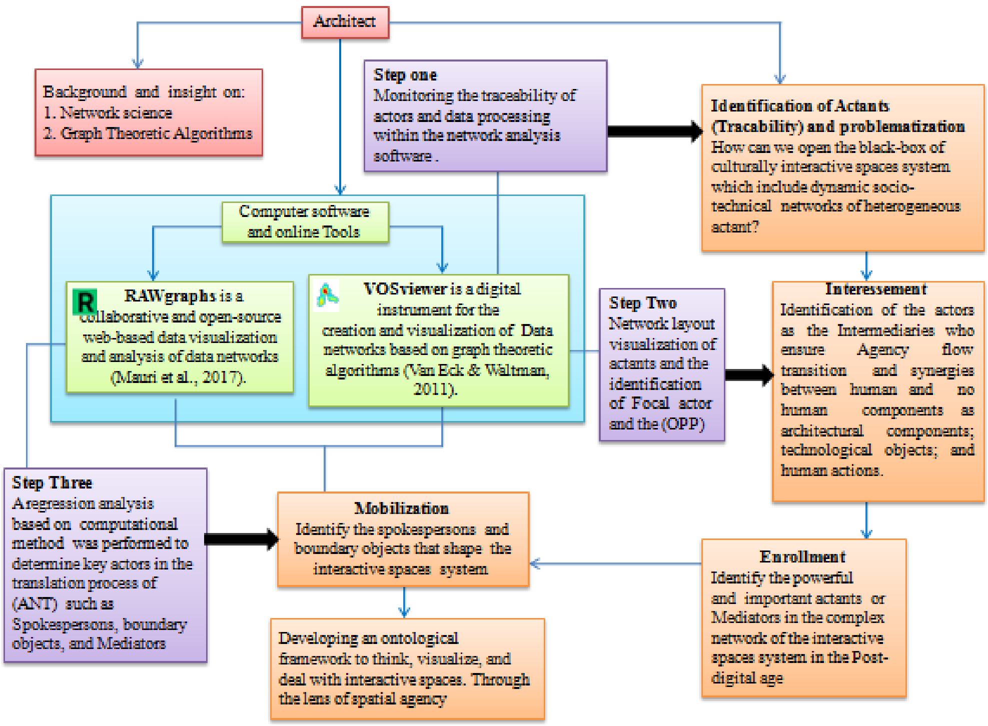

Figure 3. The procedural methodological steps
Source: Developed by Author

4. Case study description

In the preceding section, we conducted a thorough theoretical exploration to conceptualize the nature of spatial agency. Our conclusion highlighted the significant role of the digital built environment in mobilizing spatial agency by uniting diverse actors in socio-technical networks. In line with the scope and objectives of our research, we have selected a pertinent case study that encapsulates real experiences and exemplifies key concepts essential in a smart environment. The Spatially Intelligent Arts Centre project (GAC) in Geelong, Victoria, Australia (Kocaturk *et al*., 2024), funded by the Victorian State Government, was developed by an interdisciplinary team of design researchers at Deakin University in close collaboration with (GAC) staff.

The project sought to transform an Arts Centre building into a dynamic and immersing intelligent space, improving the spatial, physical and social encounters of visitors at the Performance Arts Centre while handling the crucial challenges posed by digital technology to cultural institutions today. This project provided practical guidelines in the domain of human-building interaction (HBI) and also analyzed and explored "spatial intelligence" through two complementary lenses. One lens concentrated on developing new social, spatial and experiential interactions, while the other explored opportunities to sense, capture and explore activity and movement, provide safety messaging and program-building systems to react to changing requirements in real-time, The design-research team of the project has produced various use cases classified into three conceptual frameworks, seeking to integrate and guide the principles of "spatial intelligence" within the context of the project (Kocaturk *et al*., 2024).

4.1. The first framework referred to as Interactive Co-creation

This framework aims to enable users to engage with digital content in both physical and virtual environments. For example, interactive information screens provide access to information and enable users to provide feedback. The framework encompasses four key scenarios, including:

"Talking screens": which are digital installations that facilitate conversations between patrons and digitized versions of professional (GAC) members. This promotes connections and knowledge-sharing between patrons and (GAC) professionals, as depicted in Figure 4.

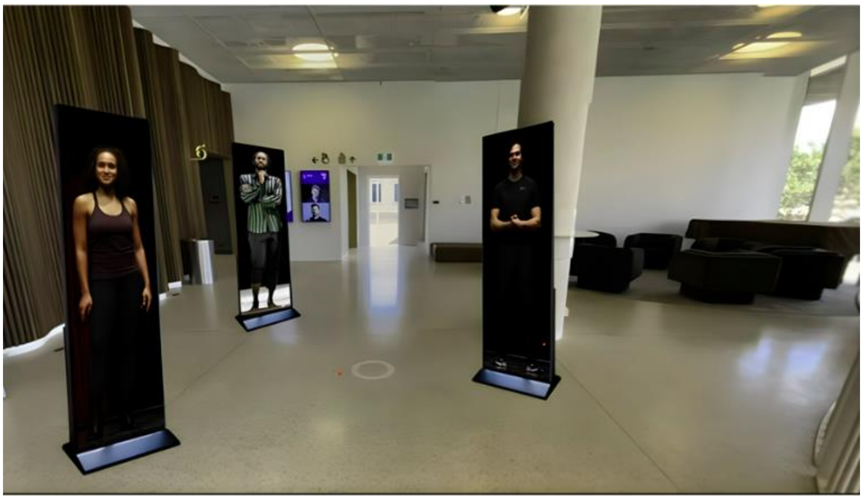

Figure 4. (GAC) foyer with three large screens that are strategically positioned to engage visitors
Source: Kocaturk et al. (2024)

“See-through walls”: An augmented reality application that allows users to monitor events in different areas of the (GAC) building, providing dynamic digital media presentations, including videos and a (3D) map of the building. This application improves the visitor experience by proposing a comprehensive view of (GAC) activities (Figure 5).

Figure 5. Displays two examples where users view dynamic digital media overlays that augment the space and reveal hidden (GAC) activities and architectural details
Source: Kocaturk et al. (2024)

“Geelong Arts Centre Spatial”: A prototype web application that hosts a (3D) model and a series of 360° panoramic images of the (GAC) building. This device enables comfortable mark-up of the GAC space for governance and communication intents, including emphasizing the location of utilities and providing space-related information (Figure 6).

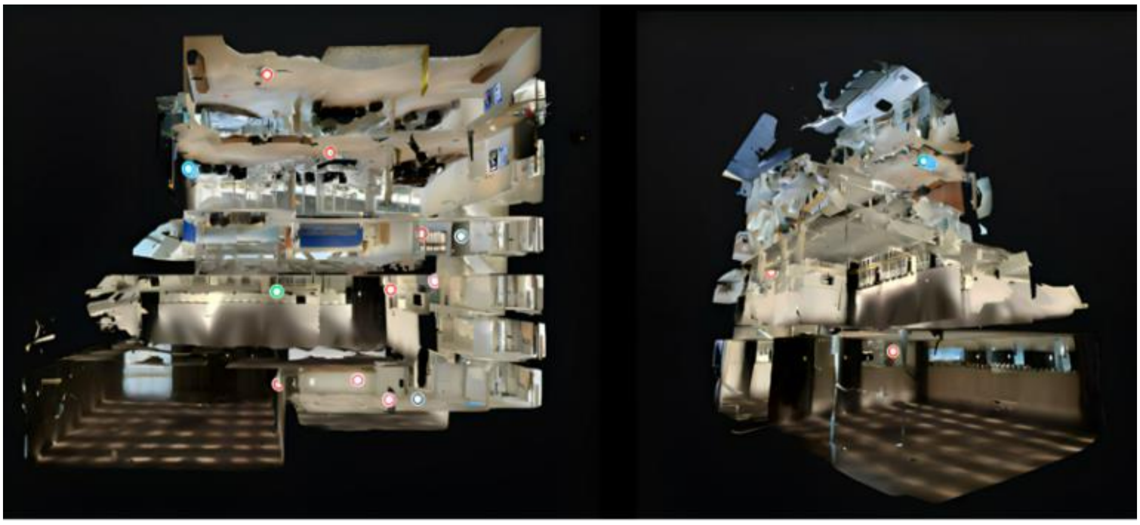

Figure 6. Spatial scan of the (GAC) building across multiple levels
Source: Kocaturk et al. (2024)

“GAC spatial with foot-traffic analytics”: An attachment of (GAC) Spatial that includes external foot-traffic data into the (3D) model of the (GAC) structure. By visualizing foot traffic patterns, it identifies congestion points. The application also suggests augmented reality features, permitting users to interact with data in real-world environments in Figure 7.

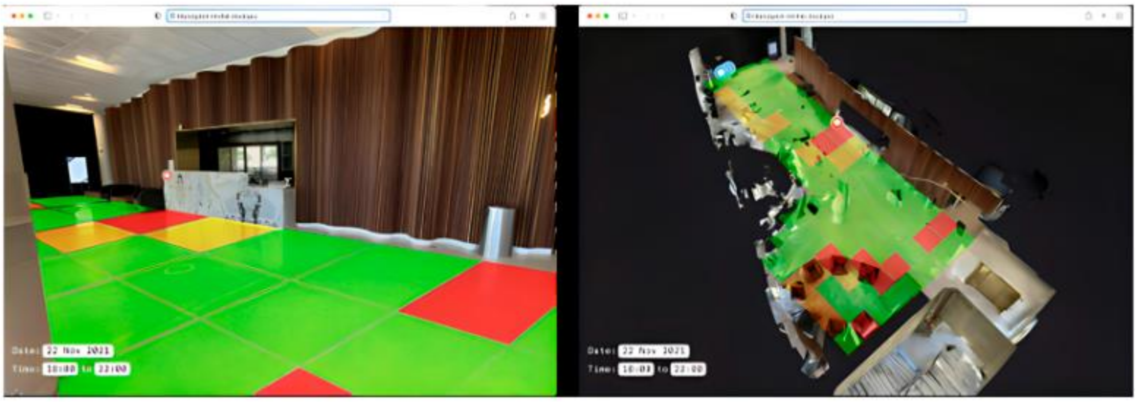

Figure 7. Simulated heat map of frequently trafficked floor areas in the (GAC) Building
Source: Kocaturk et al. (2024)

4.2. The second framework called Intelligent Navigation

This framework Permits time travel experiences to navigate via different points in time within the (GAC) context. This framework furthermore assists in analyzing visitor activity patterns to make navigation within the building easier and more informed. It suggests two scenarios:

"Virtual Windows": An augmented reality application that gives glimpses into events from the past, present and future. This innovative application helps as an exhibition attribute, providing historical insights and captivating visitors to the vast history of (GAC) and its upcoming events (Figure 8 showcases this attribute).

Figure 8. Two examples revealing past performances superimposed onto the (GAC) space, offering visitors a blend of history and modernity
Source: Kocaturk et al. (2024)

"Sliding through Time": refers to a unique sliding screen display that provides patrons access to a database containing information about (GAC) events and performances. The concept aims to create a collection of current and historical data, including archival footage, images, posters and other relevant content. This display could be used as an educational tool for school groups and as a browsing platform for patrons who want to explore GAC's archives (Figure 9).

Figure 9. Patron interacting with the display, browsing a rich database of GAC's archival footage images and posters
Source: Kocaturk et al. (2024)

4.3. The third framework called User/Location-Specific Content Activation

This framework Concentrates on sensory interaction by collecting and visualizing data associated with (GAC) activities. This framework seeks to foster and improve user engagement and operating optimization. Here are three further scenarios under this framework:

"See-through inside/outside": Harnessing projection technology both within and outside the building to make virtual visual phases aimed to immerse audiences outside the building. It provides an interactive and real-time projection that enables artful play and performance, providing those outside a glimpse of what is happening inside the building (Figure 10).

Figure 10. See-through inside/outside projection examples, where external audiences engage with interactive real-time, visuals mirroring, the building's interior activities, complemented by playful feedback mechanisms on walls and floors
Source: Kocaturk et al. (2024)

"Sentiment projection": A "living" building apt to express emotions affected by various data streams, including user feedback, social media and external news connected to the arts in the city. Sentiment analysis would detect positive or negative emotions in the collected data, which would then be displayed on the building facade through projection to visually represent the "mood of the building" to the public outside the building (Figure 11).

Figure 11. Sentiment projection concept, with the building facade dynamically illuminated to reflect the mood (from left to right: anger, fear, disgust, sadness and happiness) of the building determined by sentiment analysis of its inhabitants
Source: Kocaturk et al. (2024)

"Redirection through activation": The possibility of utilizing space usage data to direct visitors to less-frequented areas of a building is discussed in the scenario. By including interactive projections in unused spaces, guests can be motivated to investigate different parts of the building, increasing foot traffic and enhancing their overall experience. For example, by integrating captivating audio and visual effects, individuals waiting for an elevator may be encouraged to use the nearby stairway, leading to a more enjoyable and memorable visit, as depicted in Figure 12.

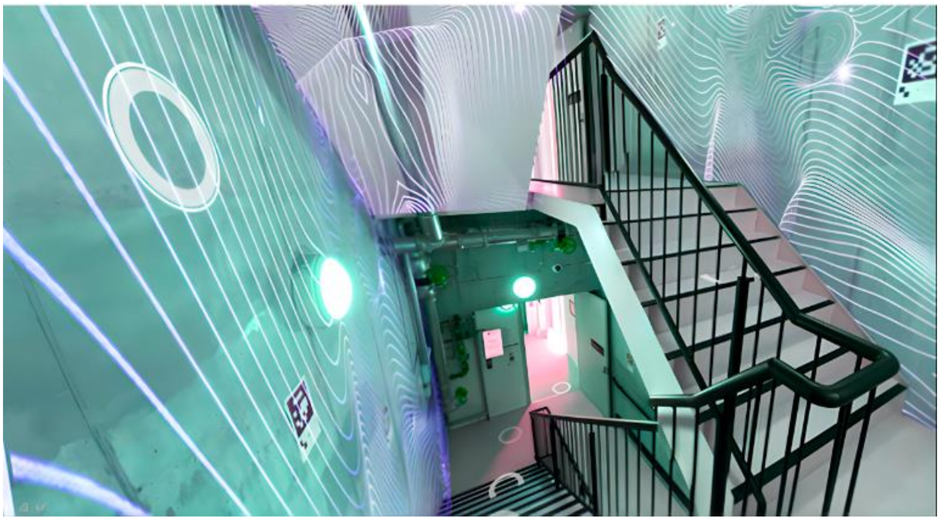

Figure 12. Interactive projection in the stairwell
Source: Kocaturk et al. (2024)

In essence, this project explores the influence of responsive interfaces on human-building interactions within a pre-existing framework. By adjusting to the changing interaction behaviors of users, the displayed information is consistently updated in real time. This demonstrates how the integration of real-time sensing and data visualization fosters a dynamic and responsive connection between individuals and the architectural environments they inhabit.

5. Results and Discussion

This section presents the findings of The present work and outlines the possibilities of the Mapping controversies technique as a practical tool to (ANT). Our results stages follow the methodology procedural steps based on the translation process of (ANT) mentioned above in the material and methods section.

5.1. Result of the first stage

In this phase, it is crucial to gather initial data relevant to the case study, known as "data input", in order to support the network analysis software used in this study to accurately represent the network structure of our case study. This aligns with the *problematization* phase as a key step in the translation process outlined by Callon's Actor-Network Theory (1984). It involves "following the actors" or tracing the influence of the actors involved in defining the problem or the observed phenomena. This phase encompasses gathering, formatting, processing and organizing data about the case study. Accordingly, the "Text mining analysis", an automated process utilizing the "VOSviewer" software based on data processing algorithms (Van Eck & Waltman, 2011), was utilized in this workflow.

5.2. Result of second stage

In the second stage, we build upon the results of the previous stage and carry out two essential steps. The initial step involves conceptualizing and visualizing actant networks based on the co-occurrence and total link strength among actors within network data input conducted in the first stage. This is achieved using various visualization techniques such as network layout visualization as seen in Figure 13 and visualization of actant density in the network as seen in Figure 14. This stage offers a preliminary response to our theoretical concern regarding the exploration of the agency of technological objects in an ontological way within the process of making interactive spaces with a focus on culturally intelligent spaces, through the analysis of characteristics and association quality of key actants that influence the dynamic network of this spaces.

The (ANT) Map displays a heterogeneous network structure composed of humane and non-humane actants articulated by nodes that represent actors, along with the important distribution of weighting among them. This weighting indicates their influence (agency) and is related to their co-occurrence within the network structure and the links between actors established by the important distribution of weight based on their total like strength. The two distinct visualization graphs Figure 13 and Figure 14 delineate the influential actants in the network, as evidenced by their high weight based on co-occurrence or height density and their height betweenness centrality, which hinges on their total link strength among other actants in the network structure. These actants are instrumental in articulating or structuring the entire system; any malfunction among them poses a substantial risk of disrupting the entire network. Within this network, The user emerges as a dominant actant with a notable weight and high betweenness centrality, aligning with Callon's (1984) definition of a "*Focal Actor"*, who aligns the interests of a diverse set of actors with their own (enacts translation). Similarly, the space holds a highly central position and weight in the network, as delineated by (Callon, 1984) as an "*Obligatory Passage Point*" (OPP) for other actors during the translation process, This "*OPP"* represents a requisite occurrence for all actors to achieve their interests, as defined by the focal actor.

The visualization offers a clear understanding of the significant players that influence the network structure. Their co-occurrence weight and centrality degree in the network, based on their overall links strength with other actors, are key factors. These actors encompass augmented reality applications, prototype web, interactive screens, wall projection, sensory interaction and data. Consequently, these entities contribute to building the network by engaging and involving more actors in the interactive design process of the "Spatially Intelligent Arts Centre project".

According to Latour (2007), mediation involves relations or associations where mediators influence the actions of other actors, which cannot always be predicted. Mediators can lead other actors to do both expected and unexpected things. When an actor enters into a relationship with another actor, they transform the original action plans into a new one. This stage aligns with the *interssement* moment of the translation process in Actor-Network Theory (ANT), where potential allies must be persuaded to act together (Prado & Baranauskas, 2013). This stage offers a primary explanation of the crucial role of spatial technologies within the interactive spaces system.

The results demonstrate that technological actants are not merely tools but active participants with substantial influence on the interactive network. This supports our hypothesis that technological components play a significant role in mediating interactions and shaping user experiences. Additionally, the identification of the user as a focal actor and the space as an (OPP) aligns with (ANT) principles. It confirms that these central actants are crucial in orchestrating the interactions and dynamics within the network, users, with their high centrality, play a pivotal role in aligning and translating the interests of various actors within the network, ensuring cohesive interaction. The space, as an (OPP) serves as a critical point through which all interactions and translations must pass, underscoring its essential role in the network. The findings align with the historical evolution of interactive spaces, where advancements in technology have shifted focus from merely enhancing building efficiency to creating responsive and engaging environments (Kocaturk *et al.*, 2024; Nabil & Kirk, 2019). The central role of technologies such as (AR), interactive screens, wall projections and sensory interactions as highlighted in the results, reflects the shift towards integrating advanced technologies to enrich user interactions and experiences, consistent with the (Tyson, 2023) concept of "*intelligent places*".

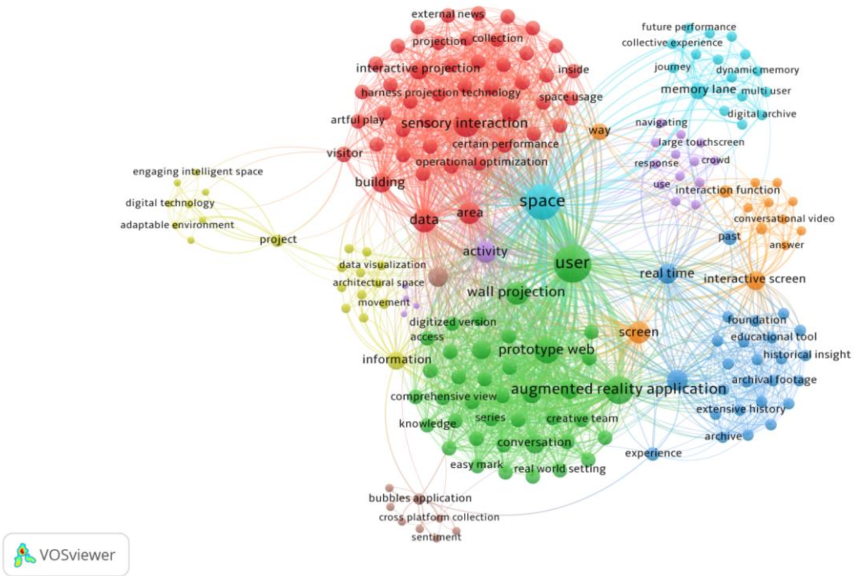

Figure 13. (ANT) Map of interactive spaces system
see full size image: https://drive.google.com/file/d/1_xdb-a1B5sYm-JhALUnx2P6vzhDJvoyB/view

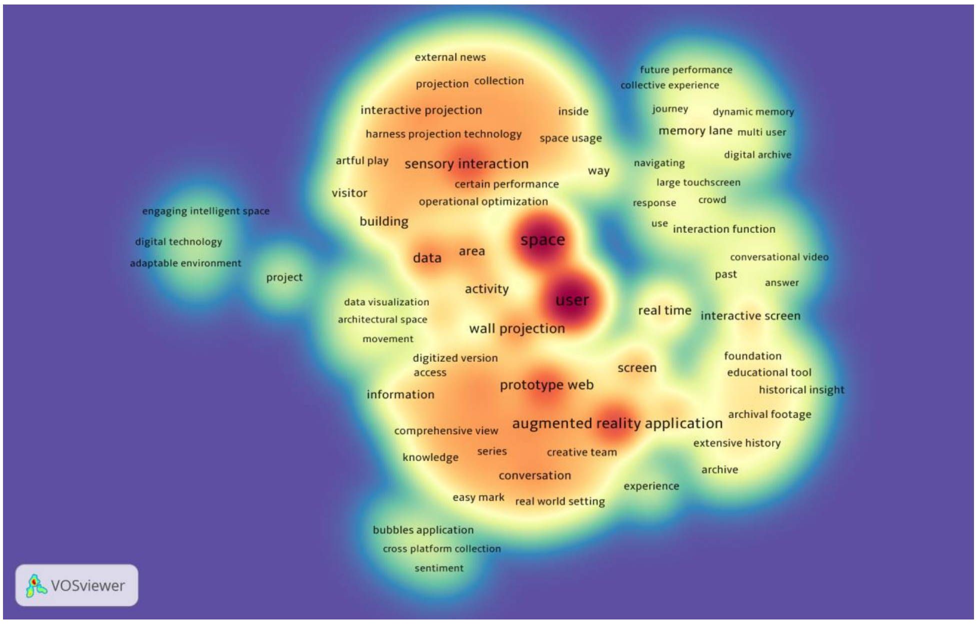

Figure 14. Map Represents the Density visualization of each actants in the network
see full size image: https://drive.google.com/file/d/1pPenYl_ZaJUZlBtsrD8xoGla-dZlTW_Q/view

5.3. Result of the third stage

In this phase, we will conduct a detailed examination of the subsystems involved in the spatial agency process within our network of case studies. To accomplish this, we will use a modularity-based calculation technique employing the community detection algorithm in the "VOSviewer" software (Waltman & Van Eck, 2013) as shown in Figure 15. This visual representation divides the actors into eight distinct subsystems or clusters based on their relationships or similar characteristics. As indicated in Figure 16, these clusters have been categorized into the following: digital interaction solutions subsystem; spatial computing subsystem; interactive media and user experience subsystem; archives and interactive learning platforms subsystem; interactive digital experiences subsystem; interactive environments subsystem; application development subsystem and smart spaces subsystem. The interaction and connection between these clusters illustrate that "The Spatially Intelligent Arts Centre project" adopts a multidisciplinary approach to enhance user integration and adaptability within spaces. Particularly, the spatial computing subsystem and the interactive media and user experience subsystem are the two most influential clusters, significantly impacting the network structure and enabling real-time control, management and communication within the project's system.

Accordingly, the Spatial computing subsystem encompasses some key actants such as external tool traffic data, prototype web, information and wall projection. Similarly, interactive media and user experience subsystems include key actants related to the enhancement of the user's perception and experience within space, such as sensory interaction, interactive projection, external news and data. This provides a comprehensive visualization of the agency of key technological actants within "The Spatially Intelligent Arts Centre project" system, contributing to the enhancement of both mental and physical aspects of the user. This phase aligns with the mobilization phase of the (ANT) translation process, whereby all actors ensure that the collaborators adhere to specific control structures to maintain their agreed-upon actions (Prado & Baranauskas, 2013). The results confirm the literature's assertion that a multidisciplinary approach enhances interactive spaces.

Accordingly, the identified subsystems demonstrate how integrating various technological and media components creates a cohesive and adaptable environment, consistent with the findings of (Kocaturk *et al.*, 2024) and (Nabil & Kirk, 2019). This supports the hypothesis that technological advancements drive the development of dynamic interactive spaces. Additionally, the role of technological actants in shaping user experiences reinforces (Latour, 2007) the concept of mediation. The detailed analysis of subsystems highlights how technological objects mediate interactions and transform user experiences, supporting the view that spatial agency is distributed across both human and non-human actors (Boychenko, 2019; Sadri, 2018). This validates the hypothesis that technological advancements lead to dynamic and adaptable interactive spaces. The analysis aligns with the (Prado & Baranauskas, 2013) description of the mobilization phase in (ANT), where actors adhere to specific control structures to maintain collaboration. The identified subsystems reflect the mobilization of actors within the network to ensure effective coordination and control, supporting the hypothesis that technological mediation plays a critical role in spatial agency.

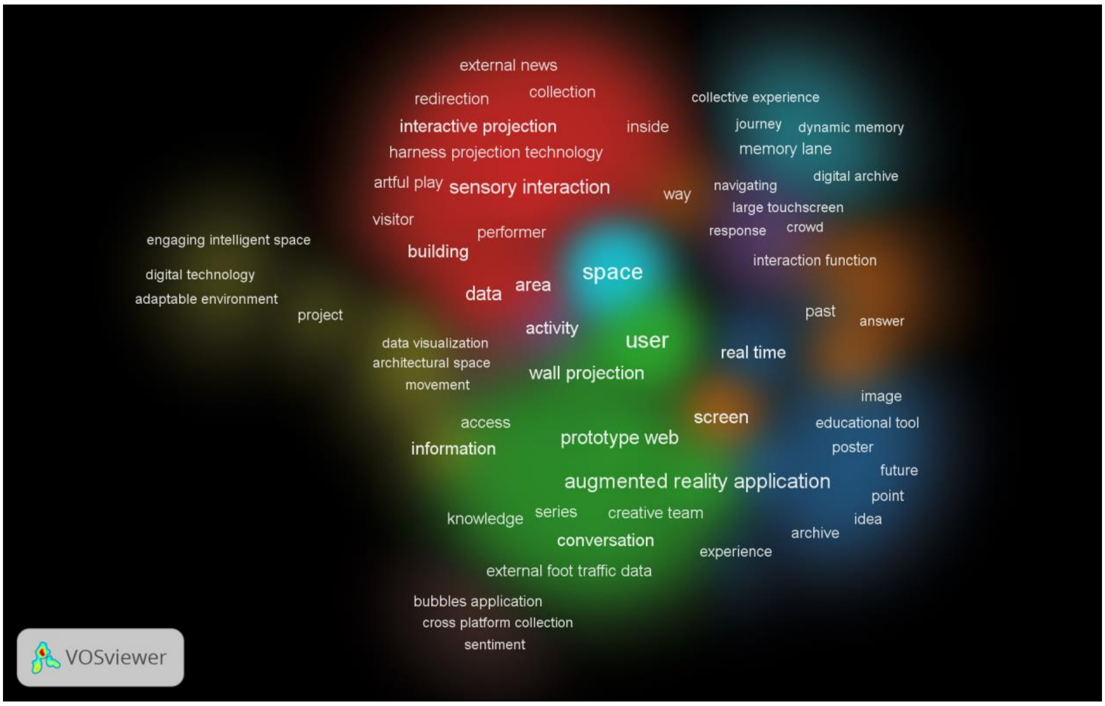

Figure 15. Map Represents a density visualization per clusters in the network
see full size image: https://drive.google.com/file/d/1W9B0xFSRjaTj6bc8E640bLloJm4pkxmf/view

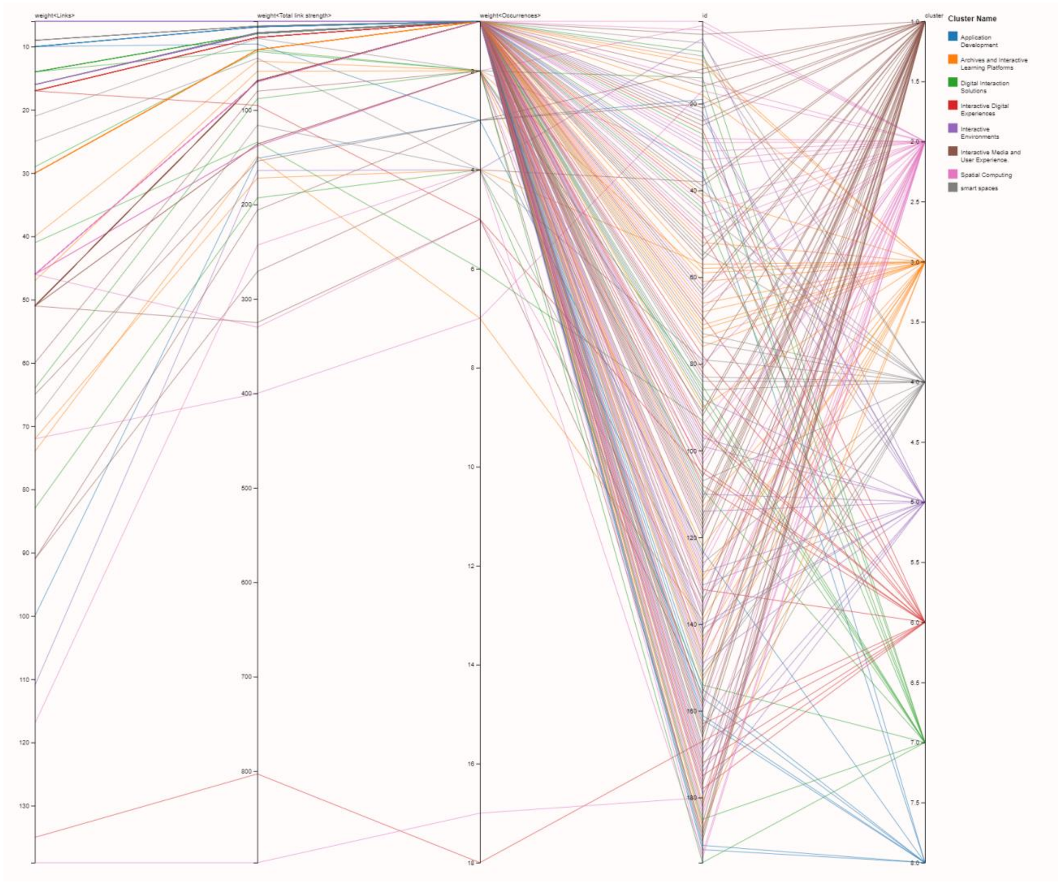

Figure 16. Map Represents a density visualizationper clusters categories
see full size image: https://drive.google.com/file/d/1KFlxIKKbPXhwItHjngsePwofuasQ6R9y/view

Additionally, a computational analysis has been conducted using graph algorithms in the "RAWgraphs" tool (Mauri *et al*., 2017) to identify the key actants in our network structure and their concordance within the key actants of the (ANT) translation process. The purpose of this analysis was to open the black box of the spatial agency process within "The Spatially Intelligent Arts Centre project" as depicted in Figure 17. Through regression analysis based on correlation graphs between two parameters the total links between the actants that give meaning to the degree centrality position of the actants in the network structure and the total links strength between the actants considering the agency (weight) of actants in the network structure, we found that the four most significant key actants in the network structure are the user, space augmented reality application and sensory interaction, which are part of different clusters.

This outcome emphasizes the essential and interdisciplinary aspects of an "intelligent place", focusing on the social aspect (user engagement), the technological aspect and the functional aspect, These outcomes emphasize the paradigm shift of "The Spatially Intelligent Arts Centre project". The central role of the user-augmented reality application and sensory interaction aligns with the work of authors like (Kocaturk *et al*., 2024) and (Nabil & Kirk, 2019) who highlight the importance of combining technological advancements with user-centric design to enhance spatial experiences. Additionally, the findings reflect the (ANT) translation process, particularly the roles of focal actors and obligatory passage points. The prominence of the user and space aligns with (Callon, 1984) definitions of Focal Actor and (OPP) respectively. This supports the hypothesis that key actants facilitate translation and interaction within the network, emphasizing their centrality in the spatial agency process.

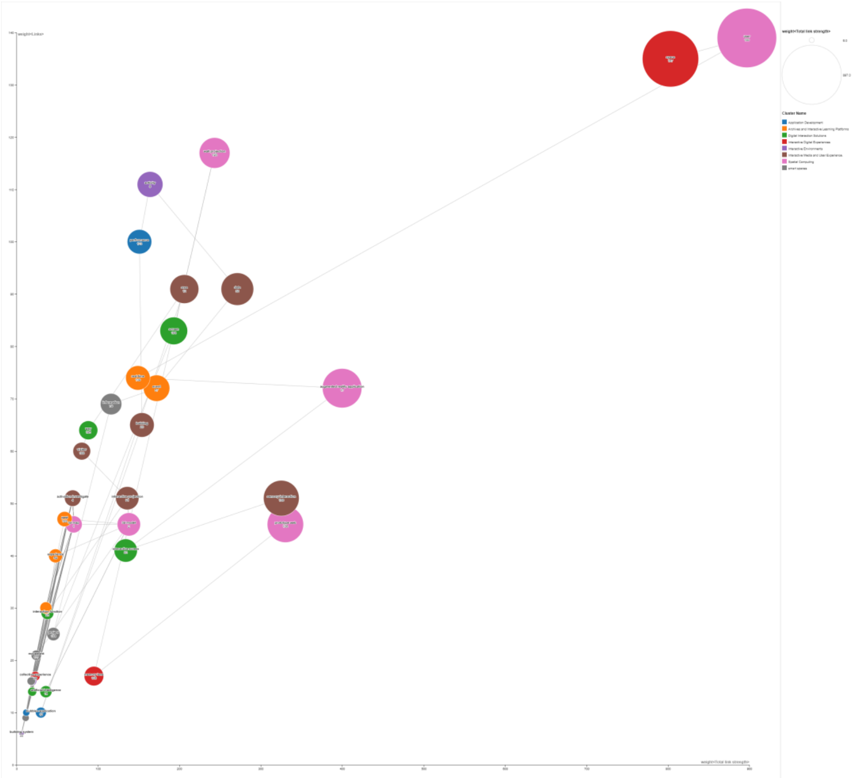

Figure 17. A graph of correlation between actants in the network
see full size image: https://drive.google.com/file/d/1ZlGa9SZI5EIjpnGWgpNTxqHCwJYBT-dD/view

In Figure 18 the main actants in each of the eight cluster distributions or sub-systems of the spatial agency process in the network of "The Spatially Intelligent Arts Centre project" are illustrated. The figure identifies the most optimal actants with the highest total links strength, considered as spokespersons in the mobilization moment of the translation process of Actor-Network Theory (Walsh & Renaud, 2010). In every group or community, spokespersons play a critical role by representing and speaking on behalf of various actors and they are essential for the success of the Actor-Network Theory (Latour, 2007). Within an actor network, the spokesperson unites different entities, known as intermediaries, to support their representations. Unlike human spokespersons, who can alter their goals (Hodgkinson & Starbuck, 2008) and are influenced by emotions (Liu & Maitlis, 2014) non-human spokespersons are more effective at maintaining network cohesion due to their consistent presence.

In this case, we have identified several spokespersons that shape different subsystems in our network structure: the screen is a spokesperson in the digital interaction solutions subsystem; while the user is a spokesperson in the spatial computing subsystem; the sensory interaction is a spokesperson in the interactive media and user experience subsystem and the event is a spokesperson in the archives and interactive learning platforms subsystem; space is a spokesperson in the interactive digital experiences subsystem and activity is a spokesperson in the interactive environments subsystem;

performance is a spokesperson in the application development subsystem; while information is spokesperson in the smart spaces subsystem.

The findings highlight the important role of non-human spokespersons in “The Spatially Intelligent Arts Centre project” network. They speak on behalf of the network, attracting more participants and spreading interest. This sheds light on the limited role of human spokespersons compared to other influential elements in the network's structure. The study by Bilodeau et al. (2019) suggests that a network requires a reliable and trustworthy spokesperson to represent and advocate for it. The spatial agency approach in “The Spatially Intelligent Arts Centre project” relies on the capabilities and performance of technological objects. The findings confirm the significance of non-human actants, such as screens and sensory interactions, in the spatial agency process. Their roles as spokespersons demonstrate their substantial impact on network coherence and user integration, supporting the idea that technological advancements are crucial in creating cohesive and interactive spaces.

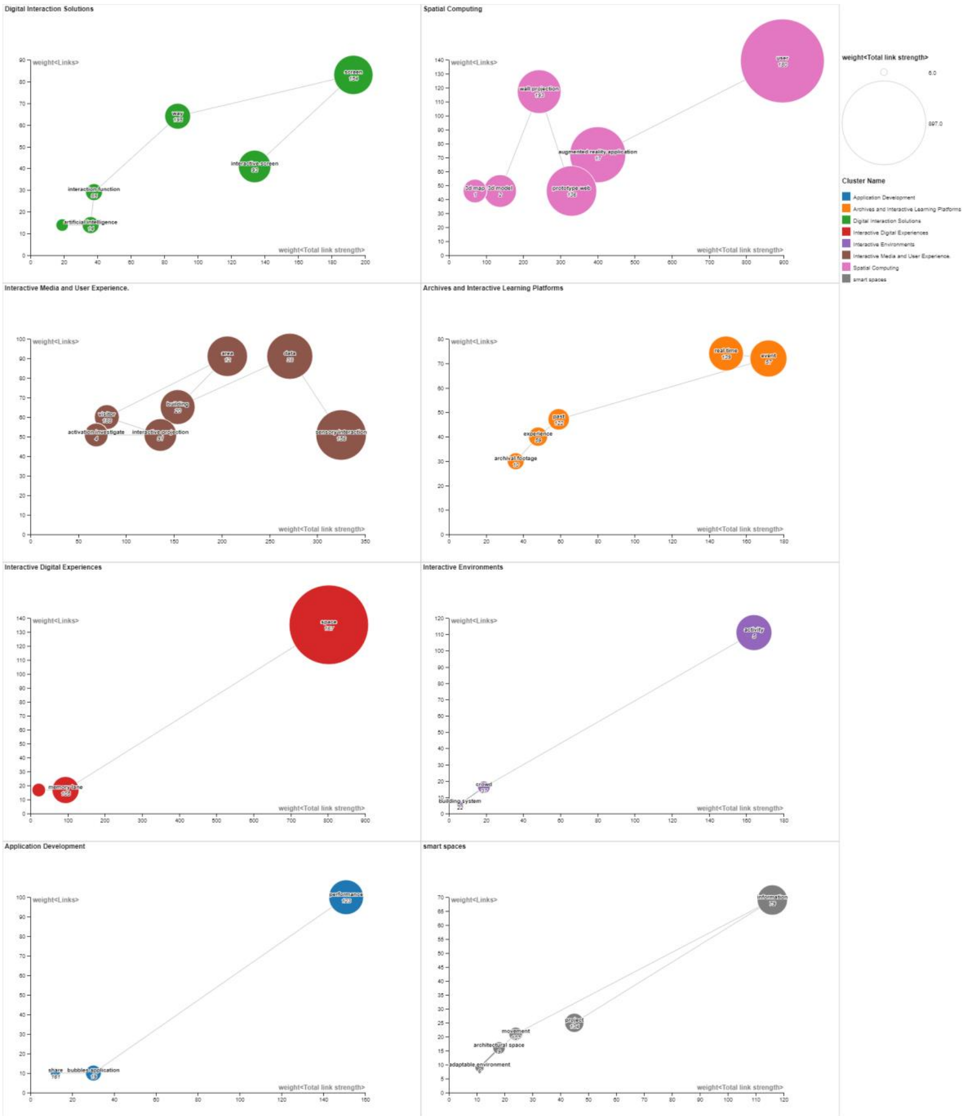

Figure 18. A graph of correlation between actants of each cluster
see full size image: https://drive.google.com/file/d/1A7k79CUAMobRshCdd05ObHgrdLgBhGvm/view

The results underscore the significance of technological actants in maintaining network stability. Al-Saigh and Mahmoud (2023) highlight how integrating visual and sensory elements like color, light and texture through intelligent materials enhances perceptual experiences and blurs architectural boundaries. This supports the findings that non-human spokespersons, such as screens and sensory interactions, play a crucial role in enhancing user interaction and spatial agency. Additionally, the Living Surface example from the study of Yu et al. (2016) demonstrates the potential of interactive surfaces that adapt based on user data, providing visual and tactile feedback. This technology exemplifies the role of non-human spokespersons in dynamic interactions within the space, aligning with the identified spokespersons in this study. The study's findings reinforce the literature on the stability of non-human spokespersons compared to human counterparts. Hodgkinson and Starbuck (2008) and Liu and Maitlis (2014) discuss the variability and emotional influence of human spokespersons, while the study of Bilodeau et al. (2019) emphasize the reliability of non-human spokespersons. The results align with these perspectives, highlighting the effectiveness of non-human spokespersons in maintaining network cohesion.

As well as within the "The Spatially Intelligent Arts Centre project" system various mediators play a crucial role in facilitating communication and progress. According to Latour (2007), a mediator is an entity that alters, converts, deforms and adjusts the course of action during the enrôlement phase of the translation process. The determination of mediators depends on the strength of the links between other heterogeneous actants in the same cluster. These mediators can take various forms, such as the prototype web, (3D) Map and (AR) application in the spatial computing sub-system; data in interactive media and user experience sub-system; activity in interactive environments sub-system information in smart spaces sub-system; interactive screen in the digital interaction solutions sub-system; bubbles application in the application development sub-system; memory lane in interactive digital experiences sub-system and real-time in archives and interactive learning platforms sub-system, as illustrated in Figure 19 for clarity.

These findings confirm the role played by spatial technologies in shaping "The Spatially Intelligent Arts Centre project" network and enabling the users to achieve their goals in the space, this is achieved just within the dominant agency of no-human objects. Accordingly, the role of mediators is consistent with the integration of intelligent technologies discussed by Al-Saigh and Mahmoud (2023). Technologies like interactive screens and (AR) applications enhance user experience and spatial interactions, aligning with the findings that non-human actants significantly influence spatial agency. The results also reflect the technological advancements highlighted by the study of Panya et al. (2023) who discuss the integration of (VR), (AR) and (BIM) technologies. These technologies facilitate communication and progress, as evidenced by the mediators identified in the study, such as the prototype web and (3D) Map.

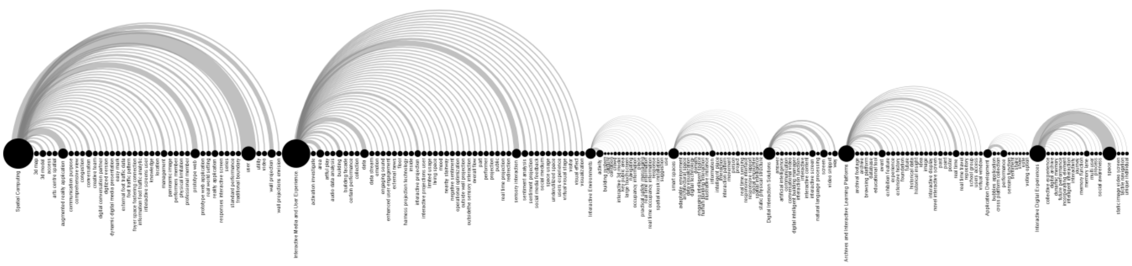

Figure 19. A linear graph of (ANT) shows the key Mediatos within each cluster
see full size image: https://drive.google.com/file/d/1PfvY9gBWMxmbec37RS622ETPFphDcmXD/view

Additionally, Boundary objects may manifest as physical items or methodologies, but they can also exist as intangible concepts or processes, provided they remain open to diverse interpretations. These entities act as connectors between disparate social groups and viewpoints, meeting local needs in ways that may not be immediately evident to outsiders (Star & Griesemer, 1989). The determination of boundary objects is based on their total links strength within all clusters in the network, where the number of point-to-point connections between actors is essential as they render networks durable and make invisible or 'black box' their inner workings (Latour, 1999). By using the fractionalization analysis method in the "VOSviewer" tool (https://www.vosviewer.com/).

This technique allows us to identify which objects serve as boundaries in the network by assigning weights to the links between nodes (actors or entities) based on the strength divides and the number of shared connections this allows us to highlight central nodes with many strong shared connections and allows to highlight nodes that link different clusters or groups within the network. For example, in our network, space can be identified as a boundary object, as illustrated in Figure 20. This crucial role of the no human is fundamental. The findings align with (Star & Griesemer, 1989) concept of boundary objects as connectors between diverse groups. The identified boundary objects, such as space, exemplify how these entities facilitate interactions and address local needs while remaining open to various interpretations. As well as the use of fractionalization analysis to identify boundary objects underscores the role of sophisticated tools in enhancing our understanding of network dynamics and spatial agency.

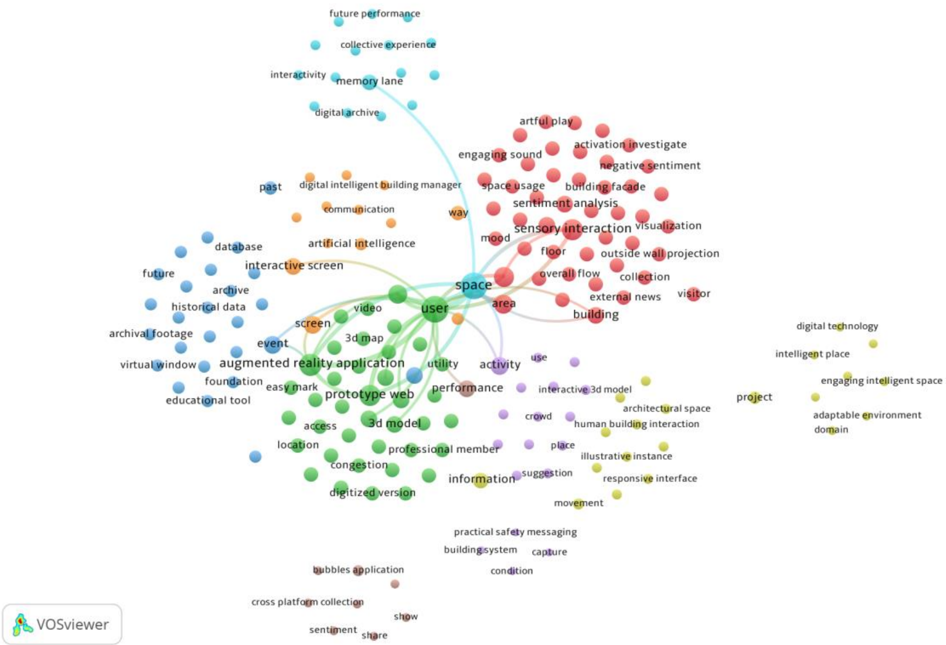

Figure 20. (ANT) Map shows Boundary objects using normalization per fractionalization method
see full size image: https://drive.google.com/file/d/1OScIsTRrOzE7ZWkkFIkLuOCmxwCihd1h/view

Moreover, gaining a thorough understanding of the influential sub-systems or dominant clusters within "The Spatially Intelligent Arts Centre project" system is essential, as depicted in Figure 21. The case study has identified key clusters or subsystems that exhibit higher levels of dominance, as indicated by the total link strength in the network. Notably, it has been established that the spatial computing cluster is the most dominant subsystem within the case study network, influencing the other subsystems. This finding emphasizes the critical role of advanced computational tools in ensuring system performance, real-time data management and the association of all actors in the network structure.

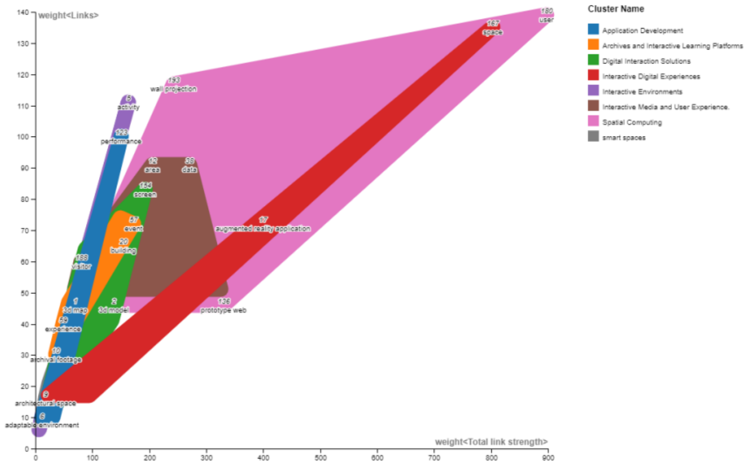

Figure 21. A computational analysis shows the most influential sub-system within interactive spaces system

see full size image: https://drive.google.com/file/d/1_EV0IvGsZBW1iHDCjBz9UyB3UX_VpTgE/view

After the integration of the results of our study with the previous research, we can provide some discussion as follows:

In our research, we utilized advanced network analysis methodologies, such as modularity-based calculations, regression analysis and fractionalization techniques, to enable (ANT) to comprehensively examine the socio-technical network of culturally intelligent spaces. This approach fills a gap in the existing literature. Previous studies, like those by Boychenko (2020) and Knox (2021), have focused mainly on real-time interactions or individual components, rather than providing a holistic view of the entire socio-technical network.

In addition, our research presents a practical ontological framework for examining the roles and the agency of technological objects in culturally intelligent environments using a procedural flow that leverages the helpful tools “Vosviewer” and “Rawgraph”. This framework enhances our theoretical understanding of (ANT) and fills the gap in ontological exploration identified in the study by (Boychenko *et al*., 2022), which focused on the role of interactive spaces and components but did not extensively delve into the visualization of ontological aspects of these technological objects and their influence within the network.

As well as Our study used the Mapping controversies technique to enable the application of the (ANT) translation process this allows us to provide a clear understanding of the role of technological objects in shaping culturally interactive spaces through a combination of a set of key actors in the (ANT) such as Focal actor, (OPP), Boundary objects and Mediators and addresses the lack of (Boychenko, 2019) study treats both human and non-human actors with equal agency but does not delve deeply into the specific contributions and roles of technological objects within these interactions.

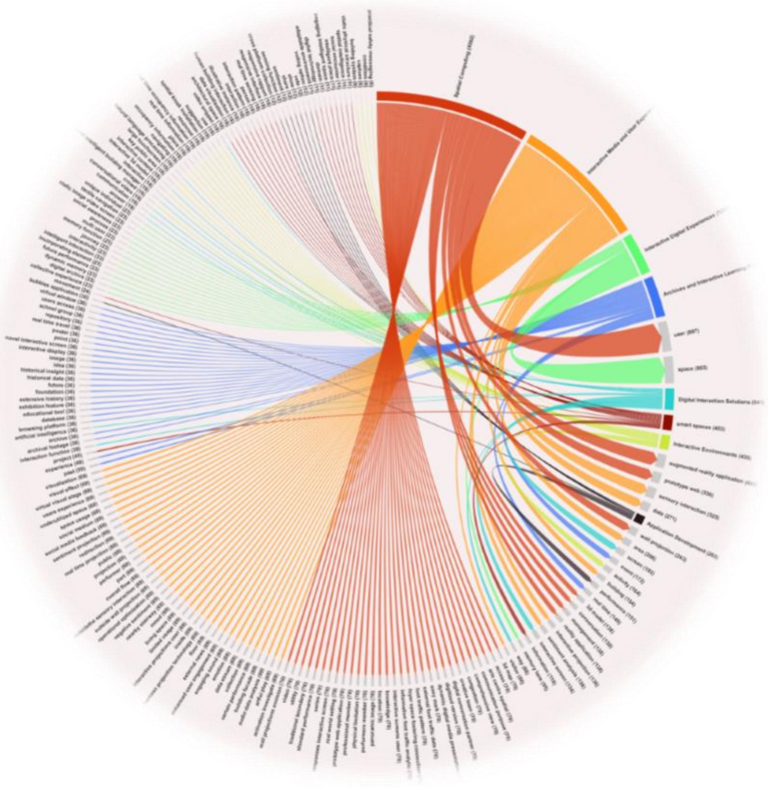

Figure 22. Other circular Map of (ANT) that represents a holistic view of spatial agency processes see full size image: https://drive.google.com/file/d/1kiK1LBt8Q7xgBfeEc35kEXYo5G032LPR/view

In addition, our study used various visualization techniques to identify a range of technological objects that influence interactive space networks. These objects include sensory interactions, augmented reality applications, memory lane and interactive projections. They contribute to environmental responsiveness and enhance user experience, adding depth to the study by (Boychenko, 2021). Despite focusing on bi-directional communication and treating architectural components and users as participants in a socio-technical network based on (ANT) to highlight the agency of interactive spaces, the study does not thoroughly explore the specific contributions of technological objects within these interactions.

To summarize the results of this research, we have presented a comprehensive and structured overview of the spatial agency process as an alternative way of thinking and making culturally intelligent buildings with a focus on “The Spatially Intelligent Arts Centre project”. Utilizing a circular diagram of actor-network theory (ANT), as depicted in Figure 22. The case study serves as a prime illustration of a system agency that embodies a fluid socio-technical network influenced by the agency of non-human actants (technological objects).

5.4. Limitations

This study acknowledges several limitations that may have influenced the results:

Scope of Case Study: The research focuses on a single case study, the 'Spatially Intelligent Arts Center'. While this case provides valuable insights, its specific context may limit the generalizability of the findings to other interactive spaces or different cultural contexts.

Complexity of Actor-Network Theory (ANT): The application of (ANT) as a methodological tool is inherently complex and can be subject to varying interpretations. This complexity may introduce potential biases in the identification and analysis of key actors and their interactions within the network.

Technological Limitations: The technologies used in the 'Spatially Intelligent Arts Center,' such as sensory devices, (AR) and Web applications, are continuously evolving. The study findings are based on the current state of these technologies and future advancements may alter the dynamics of interactive spaces and their socio-technical networks.

Data Collection and Analysis: The qualitative approach and text mining analysis in “VOSviewer” software rely heavily on the accuracy and comprehensiveness of the collected documents and texts. Any gaps or biases in the data sources could affect the validity of the network analysis and the resulting conclusions.

5.5. Implications and Recommendations

The results of this study provide significant insights and have broad implications for theory, practice and policy in the fields of architecture, spatial design and technological integration. The following recommendations aim to guide future research, practice and policy interventions.

5.5.1. Theoretical Implications

Advancement of Spatial Agency Theory: The study highlights the importance of technological objects within the spatial agency framework, emphasizing their active role in shaping interactive environments. Future theoretical work should further explore the dynamic interactions between human and non-human actors, extending the spatial agency theory to encompass a wider range of technologies and contexts. This could lead to a more nuanced understanding of how technology influences spatial dynamics and user interactions.

Integration of (ANT) in Architectural Theory: The successful application of Actor-Network Theory (ANT) in this study suggests its potential as a robust theoretical tool for examining complex socio-technical networks in architecture. Researchers should continue to refine and adapt (ANT) for architectural studies, exploring its applicability to various design processes and built environments. This integration can help bridge the gap between technology and architectural theory, offering a comprehensive framework for analyzing interactive spaces.

5.5.2. Practical Implications

ANT-Based Design Process: The Actor-Network Theory (ANT)-based design process aligns with the spatial agency approach by emphasizing the network of interactions between human and non-human actors. In the context of spatial agency, this process helps architects and designers to understand and map out how technological objects, users and environmental factors interact to create dynamic, responsive spaces. This approach ensures that spaces are not just static backgrounds but active participants in the user experience.

Integration of Digital Tools: Digital tools like (BIM) and computational design software (e.g., Rhino, Grasshopper) facilitate the spatial agency approach by enabling the visualization and simulation of complex interaction networks. These tools help designers experiment with and optimize the dynamic relationships within a space, ensuring that each element can adapt to changing conditions and user behaviors, which is a core tenet of spatial agency.

Parametric Design and Optimization: Parametric design tools allow for the creation of flexible, responsive architectural elements that can adapt to environmental inputs. This adaptability is crucial for the spatial agency approach, as it transforms built environments into interactive spaces that can respond to and shape user activities and experiences. The translation process of (ANT) helps to identify key parameters that influence these interactions, ensuring that design decisions are informed by a comprehensive understanding of the network.

Prototyping and Testing: The use of rapid prototyping and iterative testing (e.g., 3D printing, CNC machining) ensures that designs are continually refined based on real-world interactions. This aligns with the spatial agency approach by ensuring that spaces are designed not as static products but as evolving environments that can be continuously improved through feedback and adaptation.

User Feedback and Adaptation: Collecting and analyzing user feedback through digital interfaces (e.g., mobile apps and interactive kiosks) helps building managers understand user preferences and behavior. This information can be used to adjust space configurations and services, enhancing user satisfaction and engagement. The spatial agency approach, through (ANT), can identify key interaction points and optimize them for better user experiences.

5.6. Recommendations for Future Research

Scalability of Interactive Spaces: Future research should investigate the scalability of interactive spaces across different contexts and scales, from individual buildings to urban districts. This includes studying how technological innovations can be adapted to various cultural, social and economic environments, ensuring their broad applicability and impact.

Longitudinal Studies on User Experience: Conducting longitudinal studies to assess the long-term effects of interactive spaces on user experience and behavior is essential. This research can provide deeper insights into how users interact with and adapt to responsive environments over time, informing the design of more effective and user-friendly spaces.

Socio-Cultural Impact Analysis: Examining the socio-cultural impacts of interactive spaces on diverse user groups is critical for promoting inclusivity and equity. Future studies should explore how different demographics, including age, gender and socio-economic status, interact with and are affected by these environments. This research can guide the design of spaces that cater to a wide range of users, ensuring that technological advancements benefit all.

Development of Analytical Tools: Further development and refinement of analytical tools for applying (ANT) and Mapping Controversies in spatial design are needed. This includes creating more robust and user-friendly software for network analysis, enabling researchers and practitioners to visualize and understand the complex interactions within interactive spaces more effectively.

6. Conclusion

In the post-digital age, the convergence of spatial technologies such as (AR), (VR) and sensory devices has revolutionized the built environment, transforming static spaces into dynamic, interactive ecosystems. This study has explored the application of Actor-Network Theory (ANT) as a methodological and ontological tool to understand and explore the spatial agency of technological objects within interactive spaces with a focus on culturally intelligent spaces. By examining the pioneering case study of the 'Spatially Intelligent Arts Center,' we have demonstrated how (ANT) can be effectively employed to identify, visualize and analyze the complex socio-technical networks that define these adaptive environments.

Our research underscores the critical role of technological objects in shaping user experiences and operational efficiency within interactive spaces. The findings reveal that technological objects, through their agency, actively influence and are influenced by the dynamic interactions within the built environment, the results include sensory interactions, augmented reality (AR) applications, memory lane and interactive projections, all of which enhance environmental responsiveness and user experience through communication, sharing data and communication. This interplay, mapped through the translation process of (ANT), highlights the importance of considering both human and non-human actors in the design and analysis of culturally intelligent spaces.

The implications of this study are multifaceted. Theoretically, it advances the spatial agency approach by incorporating the agency of technological objects as active agents, enriching the conceptual framework for analyzing cultural interactive environments. Practically, it provides architects and designers with a robust methodology to analyze and guide the design of more adaptive and responsive cultural spaces that cater to individual user needs and preferences.

Despite the significant contributions, this study acknowledges certain limitations. The case study approach, while providing in-depth insights, may limit the generalizability of the findings. Future research should explore a broader range of contexts and scales to validate and extend the applicability of the proposed framework. Finally, this research has opened the “black box” of the spatial agency process within interactive spaces, providing a detailed ontological framework to analyze and design culturally intelligent environments. By emphasizing the agency of technological objects, we have highlighted their pivotal role in creating adaptive, responsive and immersive spaces. Future studies should focus on the scalability, socio-cultural impacts and long-term user experiences of these environments to further advance the field. Through continued exploration and innovation, we can harness the full potential of interactive spaces to enhance the quality of life in the post-digital age.

References

Ahmadi-Karvigh, S., Ghahramani, A., Becerik-Gerber, B. & Soibelman, L. (2017). One size does not fit all: Understanding user preferences for building automation systems. *Energy and Buildings*, 145, 163-173. https://doi.org/10.1016/j.enbuild.2017.04.015

Al-Saigh, M.N., Mahmoud, K.F. (2023). The impact of smart interactive technologies in creating personal internal spaces: An analytical study of user preferences for interactive shape characteristics. *International Journal of Sustainable Development & Planning*, *18*(8).

Amini, M., Mahdavinejad, M. & Bemanian, M. (2019). Future of interactive architecture in developing countries: Challenges and opportunities in case of Tehran. *Journal of Construction in Developing Countries*, *24*(1), 163-184.

Awan, N., Schneider, T. & Till, J. (2013). *Spatial Agency: Other Ways of Doing Architecture*. Routledge. https://doi.org/10.4324/9781315881249

Bilodeau, A., Galarneau, M., Lefebvre, C. & Potvin, L. (2019). Linking process and effects of intersectoral action on local neighbourhoods: Systemic modelling based on actor-network theory. *Sociology of Health & Illness*, *41*(1), 165-179.

Blok, A., Jensen, C. B. (2019). The Anthropocene event in social theory: On ways of problematizing nonhuman materiality differently. *The Sociological Review*, *67*(6), 1195-1211.

Boychenko, K. (2017). Interactive architecture: Development and implementation into the built environment. *European Journal of Technology and Design*, 5-1, 20-25. https://doi.org/10.13187/ejtd.2017.1.20

Boychenko, K. (2019). Agency of interactive architecture in socio-technological relationship through actor-network theory. In *Hello, Culture 18th International Conference, CAAD Futures 2019*, 192-202.

Boychenko, K. (2021). Re-defining the role of interactive architecture in social relationships. *Proceedings of the International Conference on GSM4Q*: *Game Set and Match IV Qatar-2019*. https://doi.org/10.29117/gsm4q.2019.0016

Boychenko, K., Boychenko, I. & Platunina, G. (2022). Agency of interactive environment in shaping users' behaviour through actor–network theory. In *Digitalization of Society, Economics and Management: A Digital Strategy Based on Post-pandemic Developments*, 163-172. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-94252-6_12

Boychenko, K., Teixeira, F.F., Kuzovkova, T. & Boychenko, I. (2020, October). Role of interactive space in social relationshops through actor-network theory. In *2020 International Conference on Engineering Management of Communication and Technology (EMCTECH)*, 1-6.

Callon, M. (1984). Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St Brieuc Bay. *The Sociological Review*, *32*(1_suppl), 196-233. https://doi.org/10.1111/j.1467- 954x.1984.tb00113.x

Callon, M. (1986). Éléments pour une sociologie de la traduction: La domestication des coquilles Saint-Jacques et des marins-pêcheurs dans la baie de Saint-Brieuc. *L'Année sociologique (1940/1948-)*, 36, 169-208.

Cheng, K., Neisch, P. (2023). A new perspective on eclectic attributes in architecture: Taking eclectic architecture in Beijing and Hong Kong as an example. *Journal of Asian Architecture and Building Engineering*, *22*(3), 1126-1145. https://doi.org/10.1080/13467581.2022.2074017

Cresswell, K.M., Worth, A. & Sheikh, A. (2010). Actor-Network Theory and its role in understanding the implementation of information technology developments in healthcare. *BMC Medical Informatics and Decision Making*, 10, 1-11.

Farías, I., Bender, T. (2012). *Urban assemblages: How Actor-Network Theory Changes Urban Studies*. Routledge.

Fenwick, T., Edwards, R. (2010). *Actor-Network Theory in Education*, 1st edition. Routledge. https://doi.org/10.4324/9780203849088

Frazer, J.H. (1993). The architectural relevance of cybernetics. *Systems Research*, *10*(3), 43-48.

Gaha, I.S. (2023). Parametric architectural design for a new city identity: Materials, environments and new applications. *Journal of Contemporary Urban Affairs*, *7*(1), 122-138. https://doi.org/10.25034/ijcua.2023.v7n1-9

Giddens, A. (1984). *The Constitution of Society: Outline of the Theory of Structuration*. University of California Press.

Guney, Y.I. (2018). Embracing today's economic and technological reality what it means for design professionals. *Journal of Contemporary Urban Affairs*, *2*(3), 107-111. https://doi.org/10.25034/ijcua.2018.4725

Hammond, M. (2018). Spatial agency: Creating new opportunities for sharing and collaboration in older people's cohousing. *Urban Science*, *2*(3), 64. https://doi.org/10.3390/urbansci2030064

Haque, U. (2007). The architectural relevance of Gordon Pask. *Architectural Design*, *77*(4), 54-61. https://doi.org/10.1002/ad.487

Haque, U., Somlai-Fischer, A. (2005). *Low Tech Sensors and Actuators*. Creative Commons.

Henri, L., Donald, N.S. (1991). *The Production of Space*. Massachusetts: Blackwell.

Hodgkinson, G.P., Starbuck, W.H. (2008). *The Oxford Handbook of Organizational Decision Making*. Oxford University Press, USA.

https://www.spatialagency.net/

https://www.vosviewer.com/

Jaskiewicz, T.J. (2013). *Towards a Methodology for Complex Adaptive Interactive Architecture*. Technische Universiteit Delft.

Knox, K. (2021, October). Communicative performance of interactive space in social relationship through actor-network theory. In *2021 International Conference on Engineering Management of Communication and Technology (EMCTECH)*, 1-6. https://doi.org/10.1109/emctech53459.2021.9619170

Kocaturk, T., Greuter, S., Hoang, T. & Wang, R. (2024). Enhancing human-building interaction and spatial experience in cultural spaces. *International Journal of Architectural Computing*, 14780771231225702. https://hdl.handle.net/10779/DRO/DU:25024757.v1

Latour, B. (1987). *Science in Action: How to Follow Scientists and Engineers through Society*. Harvard UP.

Latour, B. (1988). The politics of explanation: An alternative. *Knowledge and Reflexivity: New Frontiers in the Sociology of Knowledge*, 10, 155-176.

Latour, B. (1996). On interobjectivity. *Mind, Culture and Activity*, *3*(4), 228-245.

Latour, B. (1999). On recalling ANT. *The Sociological Review*, *47*(1_suppl), 15-25. https://doi.org/10.1111/j.1467-954x.1999.tb03480.x

Latour, B. (2007). *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oup Oxford.

Latour, B. (2017). On actor-network theory. A few clarifications plus more than a few complications. *Philosophical Literary Journal Logos*, *27*(1), 173-197. https://doi.org/10.22394/0869-5377-2017-1-173-197

Law, J. (1986). Robust statistics-the approach based on influence functions. *Journal of the Royal Statistical Society: Series D (The Statistician)*, *35*(5), 565-566.

Law, J. (1992). Notes on the theory of the actor-network: Ordering, strategy and heterogeneity. *Systems Practice*, 5, 379-393.

Law, J. (2008). On sociology and STS. *The Sociological Review*, *56*(4), 623-649. https://doi.org/10.1111/j.1467-954x.2008.00808.x

Lefebvre, H. (2014). The production of space (1991). In *The People, Place and Space Reader*, 289-293. Routledge.

Liu, F., Maitlis, S. (2014). Emotional dynamics and strategizing processes: A study of strategic conversations in top team meetings. *Journal of Management Studies*, *51*(2), 202-234.

Lorne, C. (2017). Spatial agency and practising architecture beyond buildings. *Social & Cultural Geography*, *18*(2), 268-287. https://doi.org/10.1080/14649365.2016.1174282

Marres, N. (2015). Why map issues? On controversy analysis as a digital method. *Science, Technology & Human Values*, *40*(5), 655-686. https://doi.org/10.1177/0162243915574602

Mauri, M., Elli, T., Caviglia, G., Uboldi, G. & Azzi, M. (2017). RAWGraphs: A visualisation platform to create open outputs. In *Proceedings of the 12th Biannual Conference on Italian SIGCHI Chapter*, 28, 1–5. New York: ACM. https://doi.org/10.1145/3125571.3125585

McLean, C., Hassard, J. (2004). Symmetrical absence/symmetrical absurdity: Critical notes on the production of actor-network accounts. *Journal of Management Studies*, *41*(3), 493-519.
Nabil, S., Kirk, D. (2019). Interactive interior design and personal data. *People, Personal Data and the Built Environment*, 103-122. https://doi.org/10.1007/978-3-319-70875-1_5
Negroponte, N. (1975). The architecture machine. *Computer-Aided Design*, *7*(3), 190-195. https://doi.org/10.1016/0010-4485(75)90009-3
Panya, D.S., Kim, T. & Choo, S. (2023). An interactive design change methodology using a BIM-based virtual reality and augmented reality. *Journal of Building Engineering*, 68, 106030.
Prado, A.B., Baranauskas, M.C.C. (2013). Addressing structural and dynamic features of scientific social networks through the lens of Actor-Network Theory. *Social Network Analysis and Mining*, 3, 1263-1276.
Sadri, H. (2018). Introduction: Neo-liberalism and the end of the profession of architecture. *Neo-liberalism and the Architecture of the Post Professional Era*, 1-5. https://doi.org/10.1007/978-3-319-76267-8_1
Schneider, T., Till, J. (2009). Beyond discourse: Notes on spatial agency. *Footprint*, 97-112. https://doi.org/10.59490/footprint.3.1.702
Star, S.L., Griesemer, J.R. (1989). Institutional ecology, translations and boundary objects: Amateurs and professionals in berkeley’s museum of vertebrate zoology, 1907-39. *Social Studies of Science*, *19*(3), 387-420. https://doi.org/10.1177/030631289019003001
Stark, D. (2001). Actor network theory and after. *Contemporary Sociology*, *30*(1), 96.
Strickland, A. (2014). The active agency of learning spaces. *Learning Space Design in Higher Education.* Oxfordshire: LIBRI Publishing, 209-224.
Strong, M., Letch, N. (2013). Investigating cultural heritage data integration with an ANT perspective. *Vine*, *43*(3), 322-340.
Tyson, R. (2023). From smart buildings to intelligent placemaking. Gensler. https://www.gensler.com/blog/from-smart-buildings-to-intelligent-placemaking (Accessed 4 May 2024).
Van Eck, N.J., Waltman, L. (2011). Text mining and visualization using VOSviewer. *arXiv preprint arXiv:1109.2058*. https://doi.org/10.48550/arXiv.1109.2058
Van Eck, N.J., Waltman, L. (2014). Visualizing bibliometric networks. In *Measuring Scholarly Impact: Methods and Practice*, 285-320. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-10377-8_13
Venturini, T. (2010). Diving in magma: How to explore controversies with actor-network theory. *Public Understanding of Science*, *19*(3), 258-273. https://doi.org/10.1177/0963662509102694
Venturini, T. (2012). Building on faults: How to represent controversies with digital methods. *Public Understanding of Science*, *21*(7), 796-812.
Walsh, I., Renaud, A. (2010). Translation theory revisited or change management translated. Application to a merger-acquisition case requiring a change of Information System. *Journal of Management and Future*, 39, *283-302*. https://doi.org/10.3917/mav.039.0283
Waltman, L., Van Eck, N.J. (2013). A smart local moving algorithm for large-scale modularity-based community detection. *The European Physical Journal B*, 86, 1-14. https://doi.org/10.1140/epjb/e2013-40829-0
Weiser, M. (1995). The computer for the 21st century: Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence. In *Readings in Human–Computer Interaction*, 933-940.
Wiener, N. (1988). *The Human Use of Human Beings: Cybernetics and Society*, 320. Da capo press.
Yaneva, A. (2016). *Mapping Controversies in Architecture*. Routledge.
Yu, B., Bongers, N., Van Asseldonk, A., Hu, J., Funk, M. & Feijs, L. (2016, February). LivingSurface: Biofeedback through shape-changing display. In *Proceedings of the TEI'16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*, 168-175.