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Implementing the model-based systems engineering (MBSE) approach to develop an assessment framework for healthcare facility design

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Abstract

The global elderly population rises, increasing dementia cases. Built environment impact on dementia health outcomes is known, forming the basis for evidence-based design studies. There's a need for a comprehensive assessment framework due to the complexity of interactions among Architectural Variables (AVs) and Health and Care Outcomes (HCOs). This paper proposes using Model-Based Systems Engineering (MBSE) to create such a framework. It collects data from 105 studies on 40 AVs, 36 HCOs, and 396 interactions. MBSE offers a holistic understanding, aiding healthcare facility design decisions.

Keywords: model-based systems engineering (MBSE), design evaluation, design tools, dementia-friendly design, ARCADIA

1. Introduction

The population of people with dementia is on the rise (WHO, 2024). This growing concern has drawn significant attention to solutions, both medical and non-medical, therapeutic and non-therapeutic, aimed at enhancing the health outcomes of people with dementia (Chaudhury and Cooke, 2014; Davis *et al.*, 2009; Fleming *et al.*, 2020). Among the various solutions, the design of dementia-friendly environments has proven effective and essential in enhancing the well-being of people with dementia through Evidence-Based Design (EBD) studies (Calkins, 2018; Marquardt *et al.*, 2014). Dementia-friendly design has recognized benefits for people with dementia. These include improving well-being, behavior, and functionality, enhancing confidence to explore their environment, promoting personal health, encouraging engagement in activities and social interaction, stimulating different emotional responses, and reinforcing their sense of identity (Calkins, 2018; Chaudhury and Cooke, 2014; Fleming *et al.*, 2020; Marquardt *et al.*, 2014). However, despite these benefits, there is a noticeable absence of a comprehensive and systematic tool to evaluate the effectiveness of architectural design for people with dementia in practice (Golgolnia *et al.*, 2023). One challenge in practical dementia-friendly design is the considerable number of Architectural Variables (AVs) that affect various Health and Care Outcomes (HCOs) of people with dementia. In addition, the high number of interactions among these AVs and HCOs adds further challenges. AVs can affect HCOs both directly and indirectly. In direct interactions, an AV affects an HCO in a peer-to-peer way. But in indirect effects, an AV can affect another AV, indirectly affecting an HCO. Also, when an HCO is affected, it can also affect another HCO.

The examination of the existing assessment tools reveals that they are inadequate in providing a systematic and comprehensive EBD-based evaluation for addressing the challenges mentioned above

(Calkins *et al.*, 2022; Elf *et al.*, 2017). That is mainly due to three key shortcomings. Firstly, the lack of a comprehensive development base and well-organized classification of AVs and HCOs results in their insufficient coverage. Also, the lack of focus on the target users of dementia-friendly design, namely architects and EBD researchers, leads to its limited use in architectural practice. In addition, existing assessment tools face updatability challenges. The absence of structured mediums, such as open-access databases or software, makes it difficult to effectively incorporate new research findings and updates into these assessment tools (Golgolnia *et al.*, 2023).

To address the limitations of the existing assessment tools, this paper aims to develop a new assessment framework through a systematic base. It encompasses AVs, HCOs, the different layers of their corresponding classifications, and their interactions. Also, architects and EBD researchers are clearly defined as the target users of the assessment framework. This framework also provides the possibility of being updated over time, allowing for integrating new research findings. Furthermore, it is crucial to consider all capacities, requirements, design, analysis, verification, and validation activities within the system of assessment framework. Considering all these collective requirements and the complex interactions between AVs and HCOs involved in dementia-friendly design, applying a systems engineering approach to utilize a holistic and structured capability would be beneficial.

2. Model-Based Systems Engineering (MBSE) in healthcare design

Systems engineering is a systematic approach that has been defined by the International Council on Systems Engineering (INCOSE), and is used to effectively define and design the systems ("Systems Engineering Definition", 2023). It emphasizes the definition of user needs and required system functionalities, while considering the entire system, including all its elements and their interrelationships (Haberfellner et al., 2019). It also provides a structure for designing a system, from concept development to usability (Kalvit, 2018).

Over the past few years, traditional document-based approaches in systems engineering have transitioned towards model-based approaches (Henderson and Salado, 2021). This shift is primarily due to the increasing complexity of systems and the need for more efficient and effective approaches to manage this complexity (Baron *et al.*, 2023). Model-Based Systems Engineering (MBSE), as a subset of systems engineering, is one such approach that provides methods and tools to model complex systems (Friedenthal *et al.*, 2009). MBSE enhances understanding of the system's interrelationships and dependencies, leading to more efficient development processes. It also facilitates better communication, since the models such as mathematical equations, graphs, formal expressions, or drawings (Chapurlat and Daclin, 2012) are easier to interpret than lengthy documents (Baron et al., 2023; Madni and Sievers, 2018). The models in MBSE can also be represented using various modelling languages (e.g., SysML, DSL, UML), methods (e.g., OOSEM, ARCADIA, SPES), and tools (e.g., CAPELLA, CORE, Cameo Systems Modeler, Cameo Enterprise Architecture, Papyrus) (Baron et al., 2023).

Systems engineering, particularly the MBSE approach, is well-suited for healthcare design due to the complex nature of the healthcare sector. MBSE involves understanding the elements that impact health outcomes, identifying their relationships, and modifying designs, processes, or policies accordingly to improve health outcomes and reduce costs. In contrast to the traditional systems approaches that depend on breaking elements down hierarchically, MBSE enables the development and handling of simplified models of systems, leading to a deeper understanding of their behaviours, interactions, and dependencies (Kalvit, 2018; Kopach-Konrad *et al.*, 2007). It can be applied at various healthcare system levels, from patient-clinician interactions to broader organizational and community frameworks (Kaplan *et al.*, 2013).

Incorporating the MBSE approach in the design of healthcare facilities, especially dementia care facilities, can enhance the design process and health outcomes. MBSE provides a systematic method ideal for navigating the complexities of designing dementia-friendly spaces. It provides architects and EBD researchers with a framework for managing healthcare design variables. MBSE can optimize design, boost efficiency, improve safety, and ensure regulatory compliance in healthcare facility design. In short, MBSE offers significant benefits in managing healthcare complexities, contributing to improved health outcomes (Ramos *et al.*, 2012; Zwemer and Intercax, 2016).

3. Methodology

To develop the intended assessment framework, the research scope was initially limited to the impact of AVs in nursing homes on the HCOs of people with dementia. Subsequently, a three-stage development process flowchart was defined, as shown in Figure 1. This flowchart illustrates the steps taken to incorporate MBSE into developing the assessment framework, with the previously mentioned capabilities. The first stage, pre-modelling stage, is dedicated to collecting and preparing the necessary inputs for MBSE. The second stage, modelling stage, is focused on establishing the fundamental structure of MBSE. The final stage, post-modelling stage, is based on the practical application of the framework and the validation of its effectiveness.

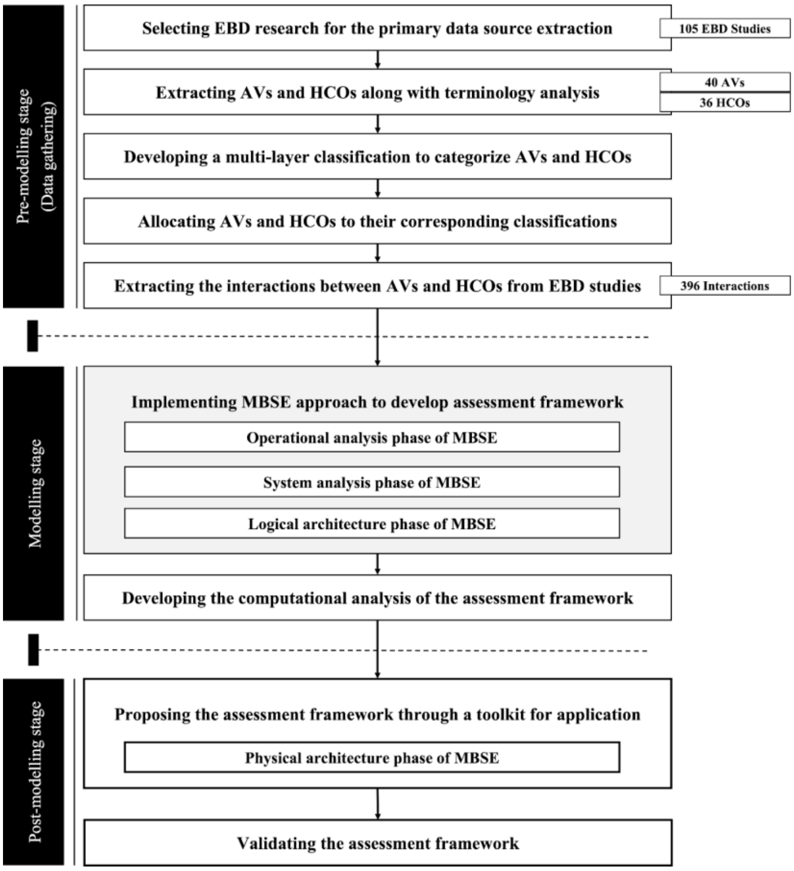


Figure 1. Development process flowchart for the assessment framework

3.1. Pre-modelling stage

The purpose of the pre-modelling stage is gathering and organising data as input for the system development. First, a body of EBD research examining the impact of AVs on HCOs was analysed to accomplish this stage. The search strategy entailed a thorough exploration of relevant literature reviews associated with EBD and dementia-friendly design. Three principal, recent literature reviews were identified and utilized for this study (review of reviews) (Calkins, 2018; Chaudhury *et al.*, 2018; Fleming *et al.*, 2020). Subsequently, the studies from these reviews (a total of 105) were obtained for an in-depth review (Golgolnia *et al.*, 2024). Then, the AVs and HCOs were identified and extracted from the EBD studies as the primary data source. This process involved identifying standardized terminologies (Golgolnia *et al.*, 2024) and developing comprehensive and multi-layer classifications for both AVs and HCOs. Then, the extracted AVs and HCOs were allocated to their corresponding classification layers. Finally, as the last part of the pre-modelling stage, the different types of interactions (396 interactions) between AVs and HCOs were extracted. During the data gathering stage, three main types of interactions were identified: the impact of AVs on HCOs (direct impact of an AV on an HCO), the impact of HCOs on HCOs (indirect impact of an AV on an HCO and then another HCO), and the impact of AVs on AVs (indirect impact of an AV on another AV and then on an HCO). These interactions were organized into a data sheet, encompassing an index referencing the EBD study, a pair of involved AV and HCO (either "to have an effect" or "to be affected"), the research findings presented as extracted statements, and an indication of whether the effect between the AVs and HCOs is positive or negative.

3.2. Modelling stage

For the implementation of MBSE in system modelling, it is essential to select an appropriate method and tool. Among different MBSE methods, the ARCADIA method with its associated tool, Capella, was used for this study. ARCADIA provides a graphical, organized, and simplified understanding of the design stage at four main phases: (1) Operational Analysis (what system users need to accomplish); (2) System Analysis (what the system must achieve for the system users); (3) Logical Architecture (how the system will work to meet expectations); and (4) Physical Architecture (how the system will be built) (Baron et al., 2023; Thales, 2023). The implementation of ARCADIA/Capella for the first three phases of this study is illustrated in Figure 2. This figure presents the key activities for each phase, the representatives of each within the assessment framework, the corresponding diagram type, and the visual representation for each activity.

3.2.1. Operational analysis

The operational analysis captures the users' needs and system context independently by identifying operational entities, operational capabilities, and the scenarios to achieve those capabilities (Arikan and Jackson, 2023; Baron *et al.*, 2023).

In this study, the operational entities are EBD researcher, architect, people with dementia (PwD), and assessment toolkit. ***(1) EBD researcher*** conducts EBD research to investigate the impact of the built environment on residents, providing scientific data that serves to update and enhance the assessment toolkit. ***(2) Architects*** design the healthcare facility, using the assessment toolkit to evaluate its alignment with dementia-friendly design principles. ***(3) PwD*** are individuals residing in healthcare facilities; their HCOs improve when the design of AVs is aligned with dementia-friendly design principles. Lastly, ***(4) assessment toolkit*** is the practical application of the dementia-friendly assessment framework, providing users with access to all its features and functionalities.

After defining the operational entities, the operational capabilities need to be outlined. Operational capabilities are the functional pillars that enable the system to achieve its goal (Arikan and Jackson, 2023; Baron *et al.*, 2023). The operational capabilities for this study, which align with addressing the challenges in existing assessment tools, could be defined as follows:

1. **Holistic Architectural Evaluation:** the assessment toolkit as a reliable source that considers the collective findings of EBD research enables architects to evaluate the design of AVs and align their designs with dementia-friendly design principles.
2. **EBD Research Management and Gap Identification:** the assessment toolkit allows EBD researchers to identify gaps in existing research and manage a dynamic database of up-to-date EBD research findings for dementia-friendly design within the assessment framework.

The ARCADIA method illustrates capabilities by defining "scenarios" designed to achieve them. Every capability must have at least one scenario to explain it (Arikan and Jackson, 2023). In this study, each capability is explained by one scenario. Thus, scenario 1 is ***Holistic Architectural Evaluation*** and scenario 2 is ***EBD Research Management and Gap Identification***.

Then, for each scenario, one Operational Architecture diagram (OAB) and one Operational Entity Scenario (OES) have been generated. OAB illustrates how the activities of operational entities interact to achieve the system's operational capabilities and, ultimately, the system goal. OES depicts the operational activities of an operational entity, including its inputs, outputs, and interactions with other operational entities. The Operational Activity Interaction diagram (Arikan and Jackson, 2023) is also used to model and illustrate the operational interactions defined within scenarios. In this diagram, three operational processes are identified: ***EBD research process***, ***update process***, and ***design process***. Scenario 1 encompasses the design process, while scenario 2 encompasses all three operational processes (*refer to the Operational Analysis section in Figure 2*).

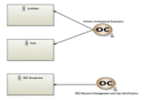
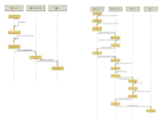
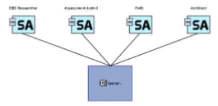
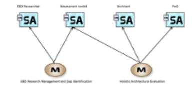
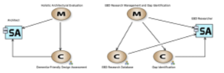
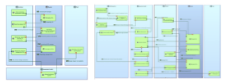
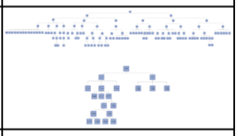
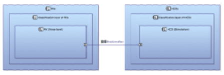
		Key activities	Assessment framework	Diagram type	Visual diagram
Operational Analysis	**Black box**	Operational entities	• Architect • EBD researcher • People with dementia (PwD) • Assessment toolkit	**OEBD** **Operational Entity Breakdown diagram**	
		Operational capabilities	1. Holistic architectural evaluation 2. EBD research management and gap identification	**OCB** **Operational Capabilities diagram**	
		Operational entity scenario	• **Scenario 1:** Holistic architectural evaluation • **Scenario 2:** EBD research management and gap identification	**OAB** **Operational Architecture diagram**	
				OES **Operational Entity Scenario diagram**	
		Operational activity interaction and operational process	• Design process • EBD research process • Update process	**Operational Processes**	
System Analysis		Contextual system actors	• Architect • EBD researcher • People with dementia (PwD) • Assessment toolkit ⊕ System	**CSA** **Contextual System Actors diagram**	
		Missions and capabilities	1. Holistic architectural evaluation 2. EBD research management and gap identification	**MB** **Mission Blank diagram**	
			• Dementia-friendly design assessment • EBD research database • Gap identification	**MCB** **Mission Capabilities Blank diagram**	
		System functions and functional exchanges	• **Scenario 1:** Holistic architectural evaluation • **Scenario 2:** EBD research management and gap identification	**SAB** **System Architecture Blank diagram**	
		Exchange scenarios	• Dementia-friendly design assessment • EBD research database • Gap identification	**ES** **Exchange Scenario**	
Logical Architecture	**White box**	Logical components	• Architectural Variables (AVs) • Health and Care Outcomes (HCOs) • Classification layers of AVs • Classification layers of HCOs	**LCBD** **Logical Component Breakdown diagram**	
				LAB **Logical Architecture Blank diagram**	
		Component in/out flow ports	• Various value of AVs • Various value of HCOs	**LAB** **Logical Architecture Blank diagram**	
		Component exchange	• Positve/negative effect of AV on HCO • Positve/negative effect of HCO on HCO • Positve/negative effect of AV on AV		

Figure 2. Integrating MBSE into the development process of assessment framework

3.2.2. System analysis

In the operational analysis phase, operational entities and capabilities were defined, and scenarios for achieving these capabilities were established. These scenarios involve functions that operational entities perform to fulfil the system operational capabilities. In the system analysis phase, the focus shifts to determining which functions belong to the system and which are allocated to external elements. These external elements are operational entities that interact with the system but are not part of it. To this purpose, the system analysis phase introduces the concept of a ***system***, an organized group of elements that operate as a unit or a "black box" (Arikan and Jackson, 2023; Baron *et al.*, 2023). In the first two phases, operational analysis and system analysis, the system has been considered a "black box." This means that the aim is to understand what enters and exits the system without focusing on the complex details of how the system processes the input to produce the output. This approach enables the analysis and understanding of the system's behaviour from an external perspective.

The operational entities were transitioned to the contextual system actors to establish the system analysis phase. In Figure 2, the Contextual System Actors (CSA) diagram represents the system actors plus the concept of the ***system***. Then, the operational capabilities were transitioned into the system missions. In Figure 2, Mission Blank (MB) diagram presents that each system actor (SA) plays the role in which mission. As an example, *Architect*, *assessment toolkit*, and *PwD* as system actors play their role in ***Holistic Architectural Evaluation*** as a mission. *Architect* uses the *assessment toolkit* to design a dementia-friendly environment for *PwD*. Then, for each mission, one or more capabilities have been defined known as ***mission capability***. The relationship between the mission, its capabilities and the related system actor is shown in Mission Capabilities Blank (MCB) diagram.

Similar to the operational analysis phase, the system analysis phase also demonstrates how system actors contribute to achieving mission capabilities. This requires illustrating what the system actors do with. Instead of viewing operational activities as ***functions*** and their interactions as ***functional exchange***, it is sugessted to establish new system-specific functions and define the interactions between them. This is essential because it outlines the specific functions that the system will perform. This is crucial as it is intended to show which functions will be performed by the system. A System Architecture Blank (SAB) diagram is created for each scenario to facilitate this. For instance, "Managing AVs" is considered a function within the system. Architect (a system actor) interacts with it through "Accessing AV Management", which is a functional exchange, as represented in the SAB diagram for each scenario.

The system analysis phase concludes with the definition of the ***exchanged scenarios***. An exchanged scenario refers to a specific workflow or sequence of events considered within the system. It's a way to define and visualize how different system elements interact with each other and external elements. A scenario diagram illustrates the relationship between a mission capability and how it is implemented. It serves as a visual guide that documents the realization of a mission capability. This diagram is instrumental in understanding the functionality of the system (Arikan and Jackson, 2023). So, three scenario diagrams for three mission capabilities, including ***Dementia-Friendly Design Assessment***, ***Gap Identification***, and ***EBD Research Database,*** have been generated without introducing new activities or functional exchange (*refer to the System Analysis section in Figure 2*).

3.2.3. Logical architecture

Following the introduction of the ***system*** concept, the focus now shifts to the system's internal elements. The logical architecture breaks down the system into its fundamental elements, known as components. These components are not physical entities. Instead, they are logical entities. The logical architecture phase allows for understanding the system at a high-level perspective (Arikan and Jackson, 2023). Essentially, this phase aligns well with the research objective of structuring and organizing the interactions between AVs and HCOs. In this phase, the system is viewed as a "white box," focusing on the internal details of the system, its constituent subsystems, and their relationships.

The internal elements in the logical architecture phase could be defined as ***logical components*** and ***logical functions***, with their relationships defined as ***component exchanges*** and ***functional exchanges***. With these definitions, various approaches can be considered for developing the logical system encompassing AVs, HCOs, their interactions, and their different values that could be adopted to each AV and HCO. For instance, colour can serve as an AV, where distinctions between red and green represent different colour values. Similarly, for HCOs, distinctions were made between positive and negative effect transmitters and recipients, representing various values. To investigate various approaches, several solutions were explored; then, one was chosen as the most aligned with the study's objectives. Table 1 presents the overview of the proposed solutions.

Table 1. Representation of logical system elements in various solutions

Solution	Representer of the classification layer	Representer of AV and HCO	Representer of interaction	Representer of AV value	Representer of HCO value
1	Logical component	Logical component	Functional exchange	Logical function	Logical function
2	Logical component	Logical component	Functional exchange	Function output port	Logical function
3	Logical component	Logical component	Component exchange	Component out flow port	Component in flow port

Solution 3 is the most suitable choice for several reasons:

a) **Representer of interaction:** Solution 3 uses "component exchange," which represents interactions between different components. This aligns well with the requirement for representing interactions in the logical system.

b) **Representer of AV and HCO:** Similar to Solution 1 and 2, Solution 3 uses a "logical component" to represent AVs and HCOs. This maintains consistency with other solutions while introducing the advantage of component exchange.

c) **Representer of AV and HCO value:** Solution 3 introduces "component in flow port" and "component out flow port" to represent the influenced and influential value of AVs and HCOs. This allows for a more precise representation of the values associated with the components.

d) **Alignment with system modelling principles:** Component exchange and the use of specific ports for values align with system modelling principles. This approach offers clarity and precision in defining the system elements and their interactions.

e) **Flexibility:** Solution 3 provides a clear separation between components and their interactions, making managing and modifying the system's structure and behaviour easier.

To implement Solution 3, the logical components have been defined through their corresponding visual diagram, the Logical Component Breakdown diagram (LCBD). The logical system consists of two subsystems: AVs and HCOs. Each subsystem is made up of components that are organized based on their specific classifications. Within each classification, there are multiple layers, each containing sublayers and components at the final level. To illustrate the hierarchical breakdown leading to a logical component like "Bright Light Exposure," its parent components include, in order, "Logical System," "Function," "Performance," "Lighting," "Light Therapy," and finally "Bright Light Exposure." Then, each of the 396 extracted interactions is presented as a component exchange. The nature of each component exchange was determined as either a "Positive effect" or a "Negative effect" based on the impact it has on other components in the system. This determination was made through a systematic analysis of the EBD research findings associated with each interaction. For instance, if a particular interaction was found to improve the AV or HCO, it was classified as a "Positive effect." Conversely, if an interaction was found to hinder the AV or HCO, it was classified as a "Negative effect" (Figure 3). These exchanges originate from a component's outflow port and connect to an inflow port. They also incorporate information such as the EBD research code and its corresponding research finding statement, serving as references for these interactions. These three phases of the ARCADIA method resulted in a Capella-based model for MBSE (*refer to Logical Architecture section in Figure 2),* demonstrated in the results section with examples of components, component exchanges, and inflow and outflow ports, highlighting their contributions to the overall system.

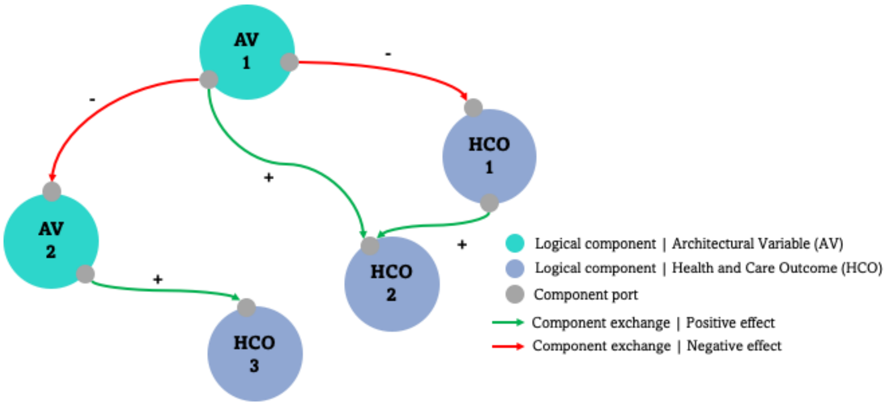


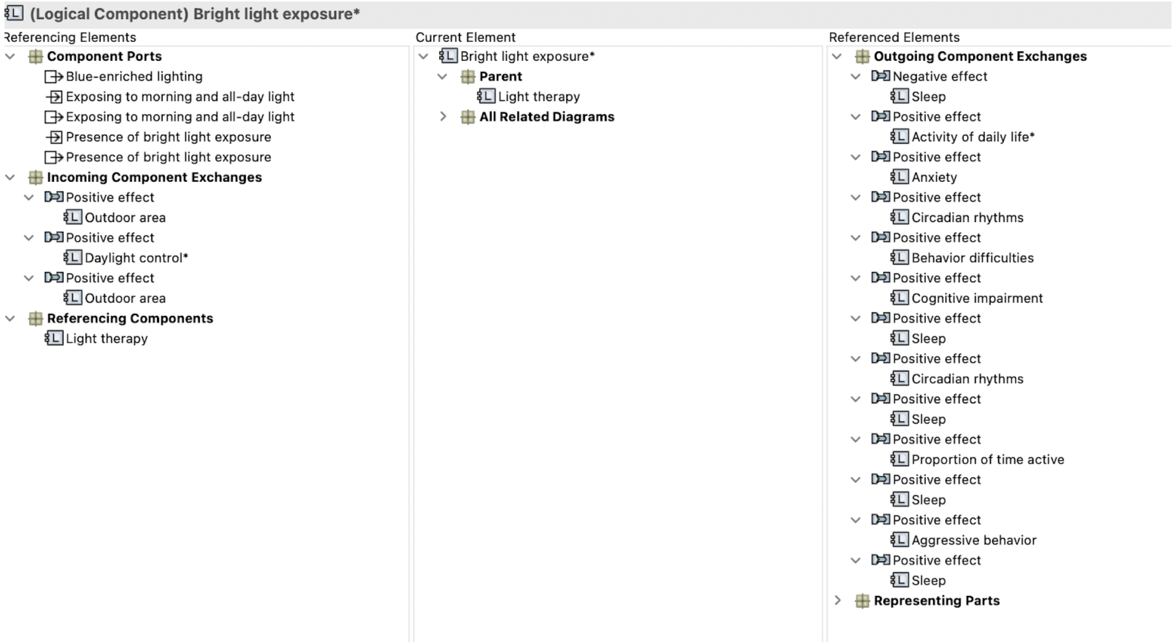
Figure 3. Causal loop diagram illustrating the component exchanges between AVs and HCOs

3.3. Post-modelling stage

The modelling stage concluded with a comprehensive Capella model, including all system components (AVs, HCOs, and classification layers) and component exchanges (interactions). In the post-modelling stage, the previously developed Capella-based model will be transferred to a web-based assessment software. This stage will focus on the physical architecture phase, the final phase of MBSE implementation. It involves constructing an assessment toolkit for practical use and developing an open-access software assessment toolkit. The practical application of this framework allows for validation and iterative improvement to achieve an optimal assessment model. The assessment toolkit enables architects to evaluate designs or existing environments, while researchers can identify research gaps in the EBD research and update the Capella model with new findings.

4. Results

After completing the modelling stage, the Semantic Browser can be accessed for each component or component exchange within the Logical Architecture Blank (LAB) diagram (Arikan and Jackson, 2023). The Semantic Browser provides comprehensive information for all 40 AVs, 36 HCOs, and 396 interactions in the Capella model. The browser presents details about the currently selected element, its referencing elements, and referenced elements. For instance, Figure 4 presents the Semantic Browser for "Bright light exposure" as an AV, with "Light therapy" identified as its final layer classification.



(Logical Component) Bright light exposure*

Referencing Elements

- **Component Ports**
  - Blue-enriched lighting
  - Exposing to morning and all-day light
  - Exposing to morning and all-day light
  - Presence of bright light exposure
  - Presence of bright light exposure
- **Incoming Component Exchanges**
  - Positive effect
    - Outdoor area
  - Positive effect
    - Daylight control*
  - Positive effect
    - Outdoor area
- **Referencing Components**
  - Light therapy

Current Element

- Bright light exposure*
  - **Parent**
    - Light therapy
  - **All Related Diagrams**

Referenced Elements

- **Outgoing Component Exchanges**
  - Negative effect
    - Sleep
  - Positive effect
    - Activity of daily life*
  - Positive effect
    - Anxiety
  - Positive effect
    - Circadian rhythms
  - Positive effect
    - Behavior difficulties
  - Positive effect
    - Cognitive impairment
  - Positive effect
    - Sleep
  - Positive effect
    - Circadian rhythms
  - Positive effect
    - Sleep
  - Positive effect
    - Proportion of time active
  - Positive effect
    - Sleep
  - Positive effect
    - Aggressive behavior
  - Positive effect
    - Sleep
- **Representing Parts**

Figure 4. Semantic Browser for "Bright light exposure" as an AV

The "Bright light exposure" component has two input ports and three output ports:

> Exposure to morning and all-day light *(component input and output ports)*, Presence of bright light exposure *(component input and output ports), and* Blue-enriched lighting *(component output port)*

These ports encompass 13 effects on various HCOs related to "Bright light exposure":

> Activity of daily life (*1 positive effect*), Anxiety (*1 positive effect*), Circadian rhythms (*2 positive effects*), Behaviour difficulties (*1 positive effect*), Cognitive impairment (*1 positive effect*), Sleep (*4 positive effects and 1 negative effect*), Proportion of time active (*1 positive effect*), and Aggressive behaviour (*1 positive effect*)

In summary, each component, exchange, and port in Figure 4 is linked to a Semantic Browser, providing additional insights accessible via the Capella model. For example, it illustrates how 'Number of residents' as an AV positively influences 'Wayfinding' as an HCO, originating from a 'Small number (7-10 residents)' in the output port of the 'Number of residents' component and targeting the 'Positive effect recipient' in the 'Wayfinding' component's input port.

5. Discussion and conclusion

This study explored the application of the MBSE approach in healthcare facility design, demonstrating its potential to address the challenges and complexities involved in developing an assessment framework for dementia-friendly designs. A review of 105 EBD studies led to the extraction of 396 interactions between AVs and HCOs, illuminating the complex interrelationship within them. The use of MBSE principles, the ARCADIA method, and Capella as a modelling tool facilitated the systematic organization and visualization of these interactions. The findings emphasized two key areas where MBSE can have a significant impact, as also noted by Crowder and Hoff (2022): ***Firstly***, the proposed assessment framework, intended for use as web-based software by architects and EBD researchers, is a key contribution of this study. Crucially, it demonstrates that MBSE provides a logical and computational engine for this software. Stakeholder feedback will further validate this, reinforcing MBSE's role as a common language and framework for dementia-friendly design. ***Secondly***, the study showcased MBSE's potential as a tool for evidence-based healthcare design. It improves the efficiency of the assessment process by automating functions across development, usability, and updates, ensuring immediate application of changes in AVs to HCOs. This holistic approach is particularly beneficial in the complex, adaptive context of healthcare design, aligning with previous studies (Kalvit, 2018; Kopach-Konrad *et al.*, 2007) on MBSE's advantages. Additionally, integrating MBSE into healthcare design can improve the design process and health outcomes (Ramos *et al.*, 2012).

In terms of the three key shortcomings identified in the introduction, this study addressed the lack of a comprehensive development base and well-organized classification of AVs and HCOs by extracting and organizing a large number of interactions from EBD studies. The focus on architects and EBD researchers as the target users of the dementia-friendly design also addressed the second shortcoming. Finally, the use of MBSE principles and tools helped to overcome the challenges related to updates faced by existing assessment tools. However, this study has its limitations. For instance, the assessment framework needs to be further developed, validated, and refined in practice. Future research could focus on integrating the logical system components, leading to the creation of a web-based assessment software during the Physical Architecture phase of MBSE. Additionally, the capacity of other MBSE modeling tools could be explored in future studies.

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