A Dynamic Model of Autobiographical Memory Effects: Applying a Cognitive Architecture to Architectural Design

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Abstract. Architectural design is a complex and dynamic cognitive activity informed by the architect's intuitions and subjectivity. Self-knowledge becomes significant as architects reflect on their existing knowledge and personal experiences, and translate them into design, shaping their overall design behaviour. Within this view, memory—and particularly autobiographical memory, understood as a dynamic and continually reconstructed cognitive resource—emerges as a key component of self-knowledge. Although design cognition research refers to memory, it has largely treated it as domain-specific knowledge derived from professional practice. Autobiographical memories arising from architects' spatial experiences, however, have not been examined as a cognitive mechanism, despite their embodied contribution. Extending beyond formal experience, their relevance has mostly been explored within critical theory rather than cognitive perspectives.

This study aims to develop a conceptual framework explaining how an architect's autobiographical memories influence design reasoning and behaviour at a cognitive level. To achieve this, two theoretical frameworks—Adaptive Control of Thought (ACT-R) and the Self-Memory System (SMS)—are integrated within a constructivist epistemology grounded in second-order cybernetics, then adapted to architectural design. An illustrative case study based on Zumthor's *Thinking Architecture* is employed, with a limited scope, to manage expectations of empirical generalisation. The findings indicate that autobiographical memories enter design cognition generally through direct retrieval of event-specific knowledge and are proceed in parallel with perceptual attention and spatial imagination. This study contributes design research with a systemic view to analyse dynamic cognitive activity of architects, with future research expected to inform design practice and education through memory-based reasoning.

Keywords: Design Cognition · Autobiographical Memory · System Thinking · ACT-R · SMS

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1 Introduction

The relationship between architectural space and human well-being is well-established research across Architecture, Psychology and Neuroscience; typically framed through environmental control and physical features. Yet, from a cognitive perspective, space also communicates with individuals at a subjective level. As Alain de Botton [1] suggests in The Architecture of Happiness, "self-knowledge" can draw people toward particular spaces in alignment with their inner states. This is especially significant for architects, who design for others while inevitably relying on their own intuitions and subjectivity.

In this sense, architecture extends beyond its physical existence and becomes entangled with emotional and cognitive dimensions. This view aligns with Semper's [2] understanding of architecture as a confrontation through which the architect situates themselves in the world, and with Pallasmaa's [3] emphasis on architecture as an extension of the designer's inner landscape into the material world. Holm [4] similarly argues that "With architecture, I space myself." [5]. Consequently, design behaviour is shaped by the architect's unconscious desires, imagined experiences of others, and—critically—their own spatial experience [6].

Although these three categories are not strictly separable, this study focuses on the latter by arguing that such an idea—an architect's personal experiences effect its design behaviour—requires a clear view of the self. In literature, the self is examined from multiple perspectives [7] and conceptualized as actual, ideal, and ought self [8]. Given this study's concern with the architect's current attributes and abilities in design behaviour, we refer specifically to the actual self, glimpsing its existing knowledge and experience. This perspective naturally leads a focus on memory, and particularly on autobiographical memory.

Human memory as a critical component of self-knowledge [7], therefore becomes central to this discussion. As a specific cognitive system, memory preserves both factual knowledge and episodic memories about personal experiences. As a mental construct, memory relies heavily on visual representations [9], a feature that makes it particularly relevant to architectural contexts. Architectural space itself facilitates memory retrieval by providing spatial and contextual cues—often imbued with emotional and narrative significance—that serve as loci for past events [10]. In this sense, architectural space and memory are closely interconnected since memories are frequently encoded together with their spatial, contextual, and affective features.

Even though such a close relation exists, design cognition studies have approached memory indirectly by focusing on its factual and domain-specific aspects. The literature has concentrated on design expertise, which refers to the accumulation of experience in architectural practice [11]. Accordingly, studies examine expert–novice differences, precedent use [12], visual analogy, analogical reasoning [13–15] and case-based reasoning. Only a limited body of study considers architects' own spatial experiences through image banks [16] and the recollection of unforgettable spatial memories [17]. This distinction indicates that design cognition research has rarely engaged with the architect's self-referential knowledge and its underlying cognitive mechanism.

Autobiographical memory, as a subset of memory, refers to the recollection of personal experiences from an individual's past [18]. Its significance lies in its support

for both coherence—the construction of a consistent life narrative—and correspondence—the accurate reflection of past events—with its dynamically reconstructed features [9]. Further, autobiographical memory supports the self with four key functions, including guiding future behaviour, forming and maintaining social networks, creating a continuous sense of identity, and coping with negative emotions and experiences [19, 20].

In architectural design, architects' autobiographical memories can influence their future design behaviour in a manner analogous to how precedents and cognitive strategies guide them for their benefit. We posit that self—coherence and correspondence—extends into the design process, shaping design reasoning and design behaviour in a creative way. Previous researches have underscored the general importance of autobiographical memory in design and small number of them have discussed the pedagogical potential of autobiographical memory, ranging from critical theory perspectives [21] to its emotional significance in design learning contexts [22]. However, these contributions remain limited, especially in the cognitive level. The underlying cognitive mechanisms remain largely unexplored.

This study aims to develop a conceptual framework that explains how an architect's autobiographical memories influence design reasoning and behaviour at a cognitive level—extending beyond formal professional experience. The proposed framework functions not only as a theoretical model but also as a methodological tool for systematically analysing the complex and dynamic cognitive activity that unfolds as an architect engages with their memory. The development of the model is guided by two research questions: (1) How can the effects of autobiographical memory be dynamically modelled within design cognition in the context of architectural design? (2) How can such a framework be methodologically applied to analyse design knowledge?

The following sections first present the theoretical foundations of the proposed model, followed by the design of an illustrative case study to both clarify the model's operational value and exploratory potential. Subsequent sections introduce the architectural design–specific conceptual framework and report the case study application and findings. The paper concludes by outlining the study's contributions, limitations, and directions for future research.

2 Methods

This section is grounded in selected theoretical frameworks and their integration within a constructivist epistemology informed by second-order cybernetics. Together, they form the methodological basis of the proposed conceptual model. Additionally, an illustrative case study, specific to architecture is also introduced.

2.1 Selection of Frameworks

Two theoretical frameworks from cognitive science are selected and introduced only to the extent needed: (1) a unified cognitive architecture capturing overall cognition, and (2) an autobiographical memory system to specifying self-related memory processes.

Adaptive Control of Thought-Rational (ACT-R). "Cognitive architecture" as one of the topics of Cognitive Science, aims to reveal the underlying mechanisms of cognition behind certain patterns of the behaviour, in an interdisciplinary area from philosophy to neuroscience. Although approximately three hundred architectures exist, most focus on specific cognitive abilities [23]. Only a few unified cognitive architectures are achieved human-like model. Anderson and colleagues' ACT-R model [24, 25] align closely with this direction due to its comprehensive memory modelling capabilities that facilitate coherent cognition, motivating its selection for this study.

ACT-R is defined as a tool to connect functional needs of the human mind with biological constraints of the brain structurally [25]. Thus, it provides both a theoretically well-established modelling to solve real-world problems with its symbolic representation and practical use through simulations by integrating the neurological mass data with a connectionist approach [24, 25]. By starting with ACT—an expansion of Human Associative Memory theory [26], which retained its declarative memory framework and extended it by introducing procedural memory—ACT-R has been developed by a community of researchers across diverse domains [27]. This study builds on ACT-R 5.0 [24] while considering the latest improvements in ACT-R 7.28+ [28]. Figure 1 provides an overview of the model.

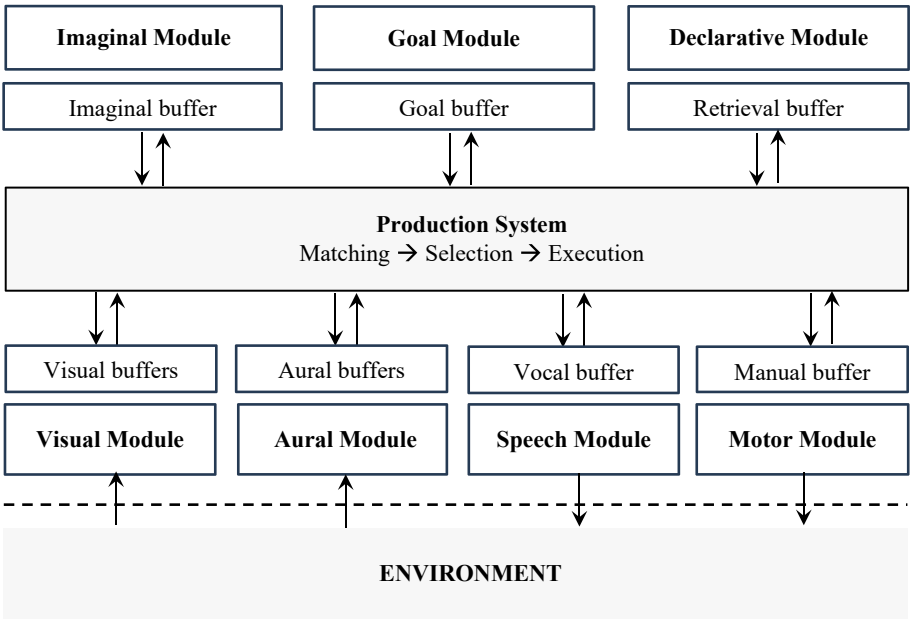

Fig. 1. Conceptual representation of ACT-R model, redrawn by authors based on [24, 28]

The model's overall cognition is achieved through a special component system that can be explained in three hierarchical levels: (a) Anderson defines this architecture as a response to Newell's scientific question: "How can the human mind occur in the physical universe?" [29]. This emphasizes both the separation and interaction between

an individual and its surroundings. It is proposed that each individual learns from the environment and subsequently adapts its cognitive process to it. Therefore, the environment—both physical and social—provides an external source of information for cognition. (b) Secondly, cognition occurs through a set of modules, in which each associates with a particular cognitive function, in a specific brain region [24]. Perceptual and motor modules differ from the others because of their direct interaction with the environment [28], thereby grounding cognition in an embodied context. The remaining modules govern diverse aspects of central processing [25], as summarized in Table 1.

Table 1. Functional roles of ACT-R model's modules

Module(s)	Functionality in general cognition
Perceptual modules	*The visual module* implements a visual attention system, which directs attention either to objects perceived directly or indirectly through the "where" and "what" subsystems. *The aural module* processes auditory events through subsystems analogous to those of the visual module [28].
Motor modules	*The motor module* facilitates motor responses, enabling actions such as hand movements. *The speech module* employs auditory input to execute appropriate responses [28].
Goal module	It manages the internal state by tracking current goals and intentions even in the absence of environmental stimuli. This ability gives humans an advantage over other species, allowing them to form abstractions for different contents and exercise self-control [24, 25]. In complex problem-solving, maintaining sub-goals to preserve local coherence is also essential [30].
Imaginal module	It contributes to the system by holding external information or current tasks as internal mental representations within its imaginal buffer [25, 28]. These representations are subsequently modified and updated by the request of production system. Additionally, this module is neurologically associated with regions involved in spatial processing [25, 31].
Declarative module Core module	This module is for retrieving information from memory to maintain long-term personal and cultural coherence [24]. Successful retrieval requires activation to exceed a threshold, determined by base-level activation (past usefulness) and associative activation (current relevance) in sub-symbolic level [24]. This module not only supports retrieval but also constructs and stores memories [25].
Procedural module Core module	The procedural module (or production system) executes cognition via production rules that respond to patterns in other modules' buffers, serving as the architecture's coordination mechanism. It manages information flow among modules selecting the highest-utility applicable rule. If needed, it requests modifications to ongoing information, and upon satisfying conditions, it executes the rule to guide behaviour through motor modules [24, 25].

(c) More specifically, each module—except the procedural one—has its own buffer. Each buffer serves as a communicator between that module and the others. It both stores limited units of information, known as "chunks," which can be requested by the production system or other buffers, and initiates requests to access relevant information from other buffers [32].

These hierarchical components work together through a delicate mechanism. The process begins with environmental stimuli, which are transmitted through perceptual modules from the environment into the mind. This information is mediated and filtered by a series of internal operations within each module, progressing in parallel along their information-processing pathways without any synchronization problem. In contrast, operations in the buffer level—such as knowledge retrieval from module to buffer and module-to-module communication—occur serially due to the limited encoding capacity of buffers. Likewise, production rules in the procedural module also fire serially, typically selecting the highest-valued rule per cycle to avoid conflict [24, 25]. All together, these processes lead motor outputs as behaviours back to the environment, completing the perception–cognition–action cycle.

Within the scope of this study, ACT-R with its unified modular system and working mechanism provides a rigorous theoretical framework to interpret architectural design cognition in general. Our focus lies here particularly on the declarative module, as it supports the retrieval of self-related memories—crucial for understanding how an architect's autobiographical memories influence its design processes.

The Self-Memory System (SMS). Conway and Pleydell-Pearce's SMS model [9, 33] provides a comprehensive framework for understanding autobiographical memory as cognitive, emotional and motivational system, drawing together insights from different fields of psychology. Its distinct contribution lies in conceptualizing the self and memory as deeply integrated that aligns closely with the purpose of this study. Owing to this feature, the model has been widely useful for examining memory dysfunctions in clinical disorders and is well supported by neurological evidence.

The model comprises two central components and one subset component, each capable of operating independently (Fig. 2); however autobiographical remembering arises only through their integration: (a) Autobiographical knowledge base is conceptualized as a memory database of the self, containing indexed memories [9, 33]. It corresponds to declarative knowledge where it encompasses both episodic and semantic forms without enforcing a strict separation—in contrast to Tulving's distinction [18]. This view is further supported by Baddeley, emphasizing that autobiographical memories are not functionally isolated but exist along a continuum within long-term memory [34]. Within this continuum, knowledge is organized hierarchically and interconnected across different levels of specificity. At the broadest level, "lifetime periods" represent extended segments of individual's life. Nested with them, "general events" capture more specific categories, encompassing both repeated experiences and single, significant occurrences. At the most detailed level, "event-specific knowledge" (ESK) consists of highly elaborated, sensory-perceptual representations of the original experience. These traces often reappear as vivid mental images and may include non-visual elements such as sounds, smells, or movements [9].

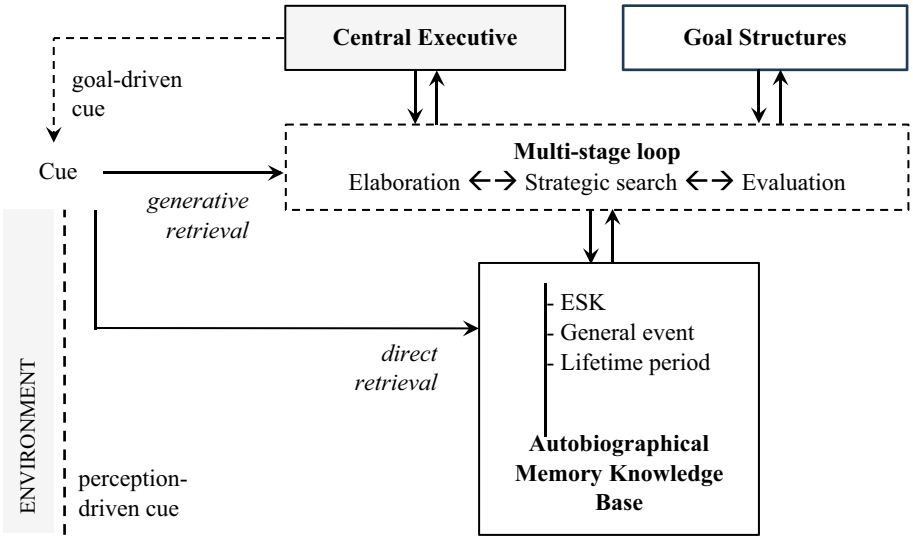

Fig. 2. Representation of SMS model, redrawn by authors based on [33] by detailing cue

(b) The other component of the system—working-self—regulates access to this base and guides both the retrieval and construction of memories [33]. It is specifically outlined for autobiographical studies in relation to Baddeley's working memory model, which evolved from the short-term memory framework [35]. As a sub-set of working memory, the working-self include "the central executive" that controls cognitive processing and closely tied with the individual's "goal structures"—the mediator between the knowledge base and the working-self [9]. (c) As a subset component, goal structures functions as filtering mechanism that preserve coherence with the individual's self-image during both memory access and construction within the knowledge base [9, 33]. Although contradictions between goals and self-knowledge are biologically possible, they are rarely sustainable in practice except in cases of clinical or neurological impairment. Beyond SMS' focus on autobiographical knowledge, goal structures are also shaped by desires, beliefs, and attitudes [9]. In addition to ensuring coherence, the working self also maintains correspondence, requiring that goals and memories align with external reality. Long-term autobiographical memories tend to favour coherence to support a stable self-narrative, whereas recent memories prioritize correspondence to preserve accuracy in relation to external events [33]. Therefore, the working-self regulates autobiographical remembering by balancing coherence with correspondence, aligning personal goals both with self-knowledge and external reality.

Through the interaction of these components, autobiographical remembering—a specific form of cognition—emerges as the central executive operates on the autobiographical knowledge base under the guidance of current goals. In SMS model, autobiographical memories are not fixed records but dynamic representations that are continually reconstructed. Accessing the knowledge base to generate such a memory proceeds through two pathways, as illustrated in Fig. 2: (a) Generative retrieval is an intentional, multi-stage process under executive control. A cue is elaborated into a preliminary memory

description, accompanied by verification criteria that guide the search. This description activates associative pathways, producing candidate information that is evaluated against the criteria. If a mismatch occurs, the system returns to elaboration until a coherent pattern is activated. Retrieval typically begins at the levels of lifetime periods or general events, which lack detailed specificity. (b) Direct retrieval occurs when a cue immediately activates a stable pattern of ESK, bypassing the generative loop. This rapid activation may yield spontaneous or involuntary recall, with goal-related modulation occurring primarily after the memory has been formed [9].

Taken together, the SMS model conceptualizes autobiographical memories as dynamic and continuously reconstructed mental representations, shaped by the individual's current goals, mental state, and contextual cues. This mechanism provides a critical framework for integrating autobiographical memory into design cognition.

2.2 Integration via Constructivism and Second-Order Cybernetics

Through ACT-R and SMS frameworks, an integration is proceeded to come up a hybrid ACT-R x SMS framework first at operational level and later epistemological level with constructivism, by referring to design cognition and architectural design.

A Hybrid ACT-R x SMS Framework at Operational Level. Within the scope of this study, ACT-R is employed to capture the general cognition, while SMS is incorporated to extend it through autobiographical memories. These two models share several functional parallels that make their operational integration feasible, with some contrasts. (a) The first parallel concerns the relationship between ACT-R's declarative module and the SMS' autobiographical knowledge base. Anderson explains the declarative module as an individual's window to the past, linking stored experiences to self-identity [26]—a perspective central to Conway and Pleydell-Pearce's model [9]. Despite this shared orientation, the models diverge fundamentally in their assumptions: ACT-R conceptualizes memory as a record—stable, retrievable chunks designed for computational simulation—whereas SMS views autobiographical memory as dynamic and continually shaped constructions.

(b) The second parallel emerges between ACT-R's goal module and production system, and SMS' working memory—goal structures and central executive. SMS model makes explicit the implicit relationship between buffers of goal and declarative modules in ACT-R: No retrieval occurs independently of the individual's current goals, emotional states, or self-related concerns. Moreover, the operational cycle of the production system (matching, selection, and execution) closely aligns with the multi-staged, generative retrieval loop described in SMS, thereby revealing how central executive control memory access and reconstruction.

(c) The final parallel is situated through cue. Since ACT-R is a unified cognitive architecture, cue is thought to enter the framework through perceptual modules from the environment at first look of the framework (Fig. 1). However, within the SMS framework, it is not well defined and functions only as an input because of SMS's domain-specific intention; only its relation through goal structures is underlined. This relation is also

appropriate in ACT-R hiddenly within goal module-to-declarative module communication. To emphasize both goal-driven and perception-driven details of cue, we made an addition in Fig. 2.

These—component-based—functional parallels enable the operational integration of the two frameworks. More specifically, the SMS model accounts for only a limited subset of the ACT-R model at the level of operations. On the other hand, contrasts between them shows the signals that two models have distinct epistemological foundations and differences in their underlying working mechanisms.

A Hybrid ACT-R x SMS Framework at Epistemological Level. Integration at the operational level is necessary but not sufficient. The essence of the proposed hybrid framework lies at the epistemological level—how cognition is understood. ACT-R is grounded in an information-processing paradigm and operates within a predominantly positivist epistemology, modelling cognition as the processing of objectively given information with simulation. By contrast, the Self-Memory System (SMS) aligns with a constructivist view that highlights the subjective, self-referential and continually reconstructed nature of autobiographical memory. Constructivism holds that knowledge is not transmitted from external reality but actively constructed through experience and interaction, thereby distinguishing objective Reality (R) from individual subjective realities (R′) [36].

A similar epistemological distinction appears in design cognition research. Problem-solving approaches, inspired by Newell and Simon, conceptualise design as a search process, whereas Schön's reflective paradigm emphasises exploration [37, 38]. ACT-R resonates with design as search, while SMS aligns with design as exploration. Contemporary studies increasingly combine these perspectives, recognising their complementary strengths. Accordingly, ACT-R provides a mechanistic account of general cognition, while SMS introduces a constructivist, more human-like dimension through autobiographical memory. This is also meaningful through our concern to place the hybrid within design cognition since we accept design knowledge is personally constructed and could be developed through lived spatial experiences encoded as autobiographical memory. This understanding of knowledge is further employed within the design pedagogy studies both for teaching and learning.

Methodologically, we situate the hybrid ACT-R x SMS within second-order cybernetics which recognises that a system cannot be explained without acknowledging the observer's participation in it. Design and cybernetics have long developed in mutual reinforcement: Cybernetics provides conceptual tools, while design offers experimental grounds for testing them. In such a test, it promotes circular causality with positioning goals as relational and internally generated rather than externally imposed [39, 40]. This explorative view aligns closely with Schön's reflection-in-action, where the designer simultaneously observes and shapes the design situation. Further, such self-aware and self-referential dynamics are evident in SMS in goal structures which mediate between the working self and the autobiographical knowledge base, influencing how memories are constructed and retrieved. Therefore, second-order cybernetics provides a perspective for interpreting SMS's not-well-defined "cue" as arising from the individual's or designer's inner organisation rather than from the external environment.

Through the integration of ACT-R and SMS frameworks; ACT-R provides the overarching structure at the operational level, whereas SMS reorients this structure epistemologically—grounded in second-order cybernetics—offering a more human-like account of how designers draw on memory in design reasoning.

2.3 Case Study Design and Analysis

This study primarily focuses on constructing a new theoretical model based on a well-defined framework and adapting it to architectural context. To add a methodological value, we rely on accessible material from architectural literature that can both meaningfully illustrate and support the model.

Following Cross's distinction that design knowledge may originate from people, processes, or designed artefacts [41, 42] our study draws specifically on first-person accounts by expert architects. Such narratives provide reflective descriptions of how designers think and act, and they resonate with autobiographical memory research, where the narrative perspective is considered indispensable [43]. Guided by this orientation, we selected a case that intentionally foregrounds autobiographical memory in relation to design thinking.

Within this context, Peter Zumthor's Thinking Architecture [44] meets this criterion. The book compiles essays written between 1988 and 1998, and provides first-person reflections that intertwine autobiographical memories, affective responses, and embodied experiences with ongoing design thinking. Further, his words on understanding architecture, strengths it's suitability for our purpose: "We all experience architecture before we have even heard the word. The roots of architectural understanding lie in our room, our house, our street, our village, our town, our landscape… The roots of our understanding of architecture lie in our childhood, in our youth; they lie in our biography. Students have to learn to work consciously with their personal biographical experiences of architecture…" While the material is not produced through a purposeful data-collection protocol, it nevertheless offers rich, memory-laden reflections that align with our analytical focus.

From this source, we selected three quotations that contain meaningful references to autobiographical memory, experience, and design reasoning. The aim was not to obtain a comprehensive material, but to work with a small number of examples. Quotations are identified as Q1, Q2 and Q3 and their cognitive focuses are underlined.

To analyse the material, we reviewed prior applications of ACT-R—the foundational framework of our hybrid model—demonstrate how it has been used to examine and represent complex behaviours. Anderson [25] highlights examples such a Salvucci's driving model and laboratory-based dual-task studies, which provide methodological guidance for mapping the cognitive processes onto the model, by a reproducible grid. Drawing on this precedent, we designed a structured procedure for the case analysis.

(1) Each selected quotation was segmented into minimal meaningful units, by identifying shifts in cognitive focus without assigning specific cognitive function. Segments were numbered in chronological order to preserve the temporal flow of the narrative, as shown in Table 2.

Table 2. Selected quotation from Thinking Architecture [44] and its segmentations

Quotation ID - Cited essay Original quotation	ID
Q1 – A way of looking at things, 1988	
"When I think about architecture, images come into my mind. Many of these images are connected with my training and work as an architect. They contain	S1
the professional knowledge about architecture that I have gathered over the years.	S1a
Some of the other images have to do with my childhood. There was a time when I experienced architecture without thinking about it.	S1b
Sometimes I can almost feel a particular door handle in my hand,	S2
a piece of metal shaped like the back of a spoon.	S2a
I used to take hold of it when I went into my aunt's garden. That door handle still seems to me like a special sign of entry into a world of different moods and smells.	S2b
I remember the sound of the gravel under my feet,	S3
the soft gleam of the waxed oak staircase,	S4
I can hear the heavy front door closing behind me	S5
as I walk along the dark corridor and	S6
enter the kitchen, the only brightly lit room in the house.	S7
Q2 – A way of looking at things, 1988	
"When we look at objects or buildings which seem to be at peace within themselves, our perception becomes calm and dulled.	S8
The objects we perceive have no message for us, they are simply there. Our perceptive faculties grow quiet, unprejudiced and uninquisitive. They reach beyond signs and symbols, they are open, empty. It is as if we could see something on which we cannot focus our consciousness. Here, in this perceptual vacuum, a memory may surface, a memory which seems to issue from the depths of time. Now, our observation of the object embraces a presentiment of the world in all its wholeness, because there is nothing that cannot be understood."	S8a S8b
Q3 – Teaching architecture, learning architecture, 1996	
"When I work on a design I allow myself to be guided by images and moods that I remember and can relate to the kind of architecture I am looking for. Most of the images that come to mind originate from my subjective experience and are only rarely accompanied by a remembered architectural commentary.	S9 S9a
While I am designing I try to find out what these images mean	S10
so that I can learn how to create a wealth of visual forms and atmospheres."	S10a

(2) We applied a coding system, based on our new model by feeding our base frameworks. Each segment was coded according to (a) its cognitive function within ACT-R's modular system, and—only if it is related with declarative module/autobiographical memory—(b) its characteristics within the SMS framework—specifically its level within the knowledge base and its retrieval type.

(3) Segments were mapped onto the new model according to their assigned codes, by following the temporal flow of narrative through a reproducible analysis grid system.

This case study is intended to illustrate the applicability of the new model within an architectural context, with particular attention to the role of autobiographical memory in design cognition. However, the approach carries inherent limitations. Because the material is not derived from a purposeful and controlled protocol study, the number of quotations is intentionally small, and introspective accounts may include selective or reconstructed elements. These constraints were acknowledged, and accordingly, the analysis is not expected to yield strong generalisations or lead to refinement of the proposed model. However, the case still has the potential to support its specific mechanisms by showing how they operate within an architectural narrative.

3 Results

In this section, we propose a conceptual framework, by adopting the hybrid ACT-R x SMS to design cognition in the context of architectural design. Later, we conduct with the case study application and then present its findings.

3.1 A Conceptual Framework: Extending Design Cognition Through Autobiographical Memories in Architectural Design

Previously, the integration of the selected frameworks at the operational and epistemological levels was established by drawing parallels with design cognition. The present section advances this integration by adapting the proposed cognitive structure from general cognition to design cognition and situating it specifically within the context of architectural design. While design spans multiple domains—such as engineering and product design—architectural design is distinguished by the complex interplay of spatial reasoning, embodiment, and external representation.

A typical architectural design process begins with the formulation of an ill-defined problem. Because such problems do not prescribe a direct solution path, the designer must first explore a broad problem space that includes project objectives, functional requirements, site conditions, legal constraints, performance criteria, stakeholder expectations, and other context-specific variables. Designers selectively prioritise these elements, often guided by intuition, personal tendencies, and prior architectural experiences. Once an initial problem frame is established, early ideas are generated through design reasoning supported by spatial imagination and external representations in a reflective, trial-and-error manner. Externalisations—such as sketches, diagrams, and three-dimensional models—reduce cognitive load and enable continuous movement between internal imagery and external marks. In parallel, relevant design knowledge is retrieved both intentionally and spontaneously to support the development of emerging concepts. The process evolves through continuous cycles of evaluation, refinement, and occasional problem reframing, eventually leading to a coherent architectural proposal.

This process is inherently non-linear, in which multiple cognitive activities operate both in parallel and in serial progress, involving perception, spatial imagination, problem

Table 3. Functional roles of the proposed framework's modules, with respect to ACT-R and SMS frameworks (AM: Autobiographical memory, CE: Central executive)

Module(s) Respect to	Functionality in design cognition in the context of architectural design
Perceptual processing modules Perceptual modules	Perceptual processing inputs as "design cues" in design can arise from a variety of sources. *Visual perception* occurs through the design brief, precedent studies expressed in drawings, sketches, or models, video materials, and visual information from project site. Parallelly, *aural perception* emerges from design conversations with a user or another architect, on-site auditory cues, and verbal or vocal research.
Motor action modules Motor modules	*Design behaviour* manifest through hand movements that externalize the designer's internal state, often using analogue or digital tools such as drawings, sketches, and modelling. These outputs, in turn, become inputs for further visual processing. *Design conversations* are defined through speech, engage aural perception and may occur with users, colleagues, or oneself, playing a crucial role in shaping design cognition, containing dialogue. Therefore, it corporates with aural perception.
Design objective Goal module, Goal structures	It serves as guiding directions in architectural design. Given the ill-defined nature of design problems, solutions emerge from multiple factors that cannot be fully anticipated by the architect's initial objectives. During the design process, even when an architect seeks local coherence, exposure to more promising alternatives—arising from research in both external and internal domains—can lead to modification of these objectives.
Spatial imagination Imaginal module	It enables architects to think three-dimensionally, including mental rotation, spatial arrangement, and perspective-taking using internal representations. Prior to—or even without—physical action, architects iteratively modify designs mentally to evaluate their suitability.

(*continued*)

framing, design knowledge retrieval, motor actions, design conversations, and design procedure rule firing shaped by the affordances of design tools. These cognitive flows are often unresolved and recur through iterative cycles of perception, cognition, and action. Although such processes cannot be directly observed within the designer's mind, they can be examined through reflective verbalisation, such as think-aloud sections or

Table 3. (*continued*)

Module(s) Respect to	Functionality in design cognition in the context of architectural design
Design knowledge Declarative module, AM knowledge base	Design knowledge is stored in the memory base, where episodic and semantic elements are intertwined, rendering them inherently autobiographical and specifying in different levels—life time period, general event and ESK. When confronted with a design brief, the architect retrieves intentionally or spontaneously relevant prior solutions based on relevant cues, facilitating the articulation and adoption of new solutions. It is further enriched through practice, skill acquisition, and spatial experience.
Design strategy Procedural module, CE	Design strategy governs the execution of design cognition by coordinating inputs from all modules. A single strategy is selected based on its guidance, determining which approach is appropriate in a given situation through if–then rules. The outcome of this cognitive process is manifested as a design behaviour.

tested through neurologically. Cognitive models, in turn, provide a structured means to systematically represent these otherwise opaque processes in meaningful analytical units. Benefiting from ACT-R's unified yet modular architecture, the proposed framework adopts modular logic and situates it within design cognition. Accordingly, Table 3 outlines the functional roles of the individual modules and their intended relevance to architectural design, with respect to functionality of ACT-R introduced in Table 1. Further SMS contributes the framework in collaboration with ACT-R, adding a value specifically on design knowledge module through a knowledge base, including different levels of specify.

Regarding these functional roles, the proposed model is presented in Fig. 3, with respect to the representations of ACT-R and SMS frameworks in Fig. 1 and Fig. 2. This framework shows adopted modules and buffers of design cognition.

In this context, certain mechanisms between modules becomes particularly prominent.

- Visual perception and design behaviour modules, and aural perception and design conversation modules are closely related due to the reflection-in-action process.
- Visual perception and spatial imagination modules are closely related due to their content domain. Since perceptual modules attend stimuli in both what and where systems, location knowledge leads primarily drives visual-spatial cognition.

- Spatial imagination module interacts continuously with the design knowledge module due to a cycle in which memory retrieval and representational changes are inherently linked. Representations are first constructed to contain their elements and subsequently modified or updated upon successful retrieval [25].
- Design knowledge module is closely related with design objective because associative activation determines the probability of retrieving a particular chunk, which is influenced by the attentional weight of the current goal and the strength of associations [25]. Therefore, retrieval could be goal-driven rather than perception-driven.

As illustrated in Fig. 3, design cognition unfolds internally in the architect's mind as much as externally through drawings, models, and other representational media.

3.2 Case Study Application and Findings

This section explicitly presents how the proposed framework is applied to the case study in a systematic and reproducible manner and comes up with limited findings on revealing how autobiographical memory can be traced in the architect's reflections. This is achieved by operationalising the theoretical model and enabling a micro-level analysis through design cognition.

Material. As presented before in Table 2, three quotations were selected and further segmented into a total of 10 meaningful cognitive units, each defined by a shift in cognitive focus. These segments constituted the material for the case study analysis.

Mapping into the Proposed Framework. A set of explicit rules is required to establish a systemic level of analysis. All variables, identified in the coding system, constitute the dimensions of the mapping presented in Table 4. The rows correspond to the segmentations, and the columns represent the variables of the proposed framework. Activation in modules are indicated through notation of segment ID or if necessary, by text. Retrieval type and knowledge level are only reported when design knowledge module is notated. This coding system functions as a reproducible micro-level analytical and visualisation tool through which the case material is mapped onto the proposed framework.

Findings. Table 4 illustrates that the proposed framework can be practically applied to reflective textual material, resulting in a coherent and systematic analytical perspective. Yet, more than illustrating applicability, the case study also supports the framework by making explicit several findings through the mapping.

- The three quotations reflect different emphases in autobiographical remembering and together show how such memories dynamically enter and shape architectural design reasoning: Q1 foregrounds the perceptual richness of autobiographical memories, providing insight into how early-life experiences. Q2 highlights the role of perceptual stimulation in triggering memory spontaneously. Q3 shows how autobiographical design knowledge feeds to design reasoning, particularly through meaning-making.
- Even though those quotations make explicit that Zumthor's design reasoning is deeply interwoven with autobiographical memory, quotations do not describe design action in a procedural sense due to the reflective nature of the material. Parallel processing across modules—in any segment—is more clearly seen than seriality (S5, S6, S7).

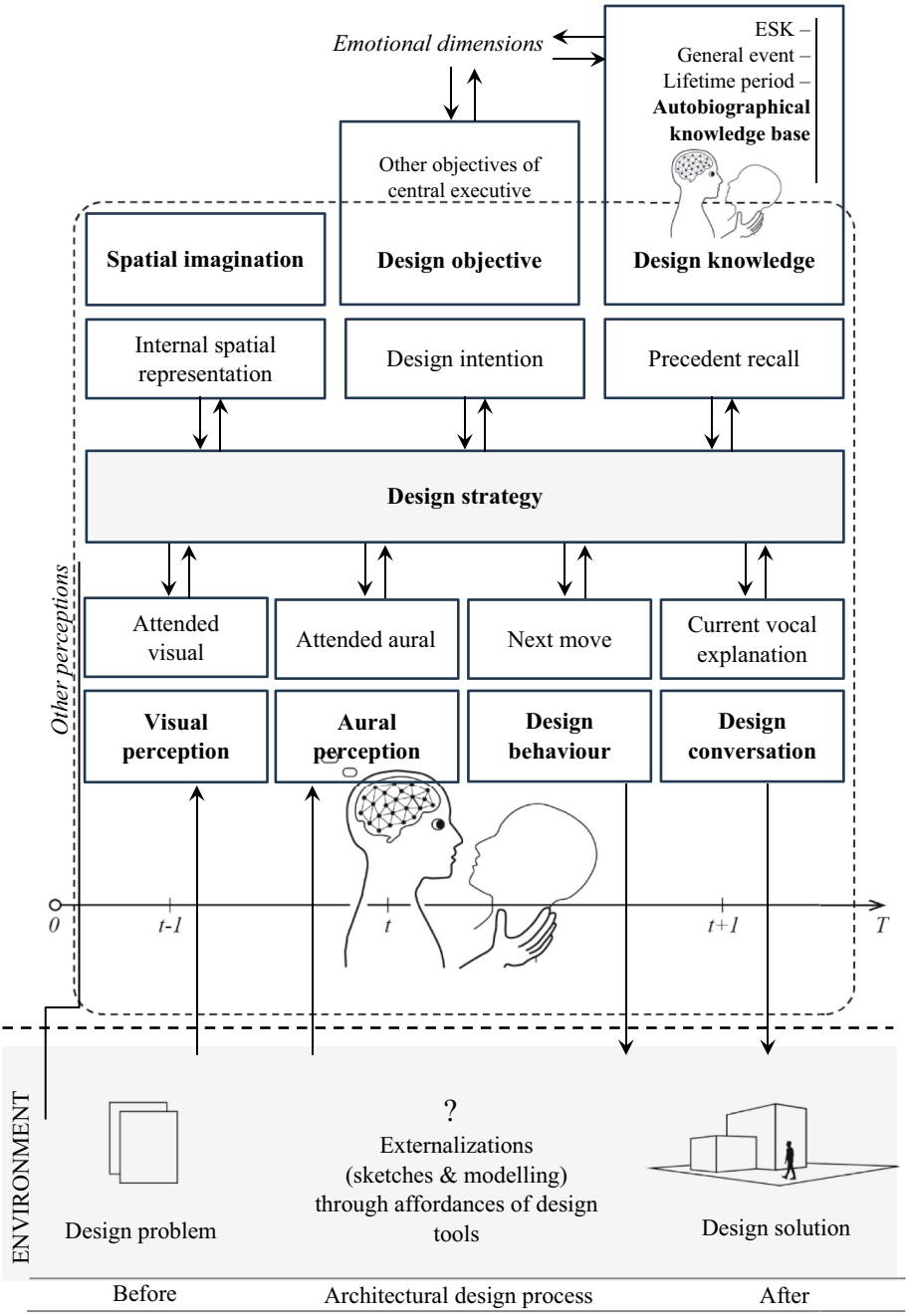

Fig. 3. Representation of the proposed conceptual framework (adopted to the context of architectural design from the hybrid ACT-R x SMS, by enriching with emotional dimension and other perceptions) (t: time, 0: start, T: end)

Table 4. Mapping of the segmented quotations into the proposed model (PPM: Perceptual processing modules, V: Visual perception, A: Aural perception, O: Other perceptions; DS: Design strategy; SI: Spatial imagination; DO: Design objective; DK: Design knowledge; MAM: Motor action modules, B: Design behaviour, C: Design conversation) (r: retrieval, ESK: Event-specific knowledge) (W-T: When / While – then, S-T: So that)

Quotation ID Segment ID	PPM			DS	SI	DO	DK	MAM		Retrieval type Knowledge's level
	V	A	O					B	C	
Q1										
S1	–	–	–	Start W-T	–	– Think	– S1 S1a S1b	–	–	– Generative r. Life-time period-1 Life-time period-2
S2	– S2a	–	S2	–	– S2a	–	S2 S2a S2b	–	–	Direct r. ESK General event
S3	–	S3	S3	–		–	S3	–	–	Direct r., ESK
S4	–	S4	S4	–	–	–	S4	–	–	Direct r., ESK
S5	S5	S5	–	–	S5	–	S5	–	–	Direct r., ESK
S6	S6	S6	–	–	S6	–	S6	–	–	Direct r., ESK
S7	S7	S7	–	–	S7	–	S7	–	–	Direct r., ESK
Q2										
S8	– S8	–	–	Start W-T	–	– Look	– S8a S8b	–	–	– Direct r., ESK
Q3										
S9	– S9a	– S9a	– S9a	Start W-T	– S9a	– Work	– S9 S9a	–	–	– Direct r. ESK
S10	–	–	–	W-T S-T	–	Find Learn	S10 S10a	–	–	Generative r. General event

- Each quotation begins with the firing of a procedural rule triggered by different module demands; goal-driven in Q1 and Q3, perception-driven in Q2. This confirms that autobiographical memory can enter design cognition through both intentional and involuntary pathways.
- Zumthor's use of language such as when–then (S1, S8, S9), while–then (S10), and so that (S10a) mirrors ACT-R's if–then production logic.
- Segments S2a, S3, S5, S6, S7, and S9a all show that design knowledge retrieval frequently co-occurs with perceptual attention and spatial imagination. Visual attention strongly dominates this interaction, supporting the notion that autobiographical memory is image-based, while spatial imagination relies on the perceptual modules' where system. Aural and bodily perceptions (S3, S5) also participate in these parallel processes, underscoring the embodied character of remembering.
- Direct retrievals of ESK is frequently seen, confirming that sensory-dominant autobiographical memories play a significant role in the architect's imagery. At the same

time, generative retrieval appears in S1 and S10, where Zumthor explicitly searches for meaning and connects memories across different levels of specificity.

This analytical process also revealed several directions for potential refinement of the framework. Emotional dimensions and non-visual perceptual modalities, beyond the visual and aural, should be more explicitly incorporated, as they are evident across all three quotations; these aspects are already acknowledged in Fig. 3. In addition, chunk-like associative structures deserve particular attention, as exemplified in S2b by the link between the door handle and the atmosphere of the aunt's garden.

Overall, the findings indicate that memory-based design reasoning is characterised by parallel, reflexive, and embodied processing, through which architects transform personal memories into material for architectural thought.

4 Discussion

4.1 Contributions

This study is motivated by the observation that, in the existing literature, autobiographical memory is only limitedly addressed at the cognitive level in architectural design, and its underlying cognitive mechanisms remain largely unexplored. Considering this gap, the study is shaped by two core research questions: (1) How can the effects of autobiographical memory be dynamically modelled within design cognition in the context of architectural design? (2) How can such a framework be methodologically applied to analyse design knowledge?

Regarding the first research question, we propose a theoretical framework by employing ACT-R for overall cognition [24, 25] and SMS for self-related memory [9, 33], both originating from cognitive science. These are subsequently integrated through a constructivist epistemology, grounded by second-order cybernetics, and finally adapted to design cognition within the architectural context. This comprehensive framework effectively explains how an architect's autobiographical memories influence design reasoning and behaviour at a cognitive level, extending the analysis beyond formal professional experience. This directly addresses the identified gap: While design cognition literature has extensively examined expertise, precedent use, and in-domain memory, it has not adequately accounted for self-referential and emotionally grounded autobiographical memories.

In response to the second research question, we employed established design cognition methodological guidance, leveraging the potentials of the base frameworks, and enriched the study by conveying a case analysis based on Zumthor's reflections on architectural design. For analysing such a case, we produce a systemic and analytic view capable of capturing the dynamic cognitive activity of architects through the effects of autobiographical memory. Even though the analysis is limited to an architect's reflections within the scope of this study, this view is conveniently applicable to broader design cognition studies, which are typically pursued through protocol studies supported by controlled experimental design [45].

These theoretical and methodological contributions collectively close a significant conceptual gap in design cognition by emphasizing autobiographical memory as an active and reconstructive cognitive mechanism that profoundly shapes design reasoning and subsequent design behaviour. This also helps to position the proposed framework within the relevant paradigmatic perspectives. For instance, within the problem-solving paradigm, Akın [46] similarly adapted Simon and Newell's information-processing system to architectural design, symbolically including memory as a component. However, that framework predominantly explains design cognition at an abstracted, macro-level by concentrating on the overall structure of the designer's mind. Conversely, Schön's reflection-in-action [47] highlights the situated and emergent nature of design reasoning but remains primarily descriptive. Therefore, our proposed framework—based on the hybrid ACT-R x SMS—is situated between these two approaches. It endeavours both to mechanistically systematize how autobiographical memories enter the cognitive cycle and exploratorily discover the potentials of different autobiographical memories, all through micro-level processing. This situation can be summarized as the modelling of how lived experience—encoded hierarchically in autobiographical knowledge and retrieved generatively or directly—actively shapes spatial imagination, design objectives, and design strategies. In this context, the effects of memories can be systematically captured.

Further, this study contributes significantly to both architectural theory and ACT-R research through the adoption of constructivist epistemology and second-order cybernetics, by the integration of the SMS. Traditionally, ACT-R has been treated as a mechanistic information-processing model via a simulation program, viewing memory as a storage of fixed representations. Even though Anderson [25] acknowledges that declarative module operates via a specific—sub-symbolic—mechanism, it fundamentally relies on well-defined "chunks." However, when ACT-R is viewed through a constructivist lens, this changes, and memory becomes a constantly shaped and transitory element, dependent on perception-driven or goal-driven cues. This perspective is radically strengthened by the integration of second-order cybernetics, as self-reflection is incorporated into the system. This is achieved by redefining the goal module with a new internally-focused relation to the declarative module, thereby including the emotional aspects (Fig. 3, for architectural design)—a feature of the individual designer often neglected in purely mechanistic cognitive models. Consequently, ACT-R, when combined with constructivism and reflexivity to past experiences, evolves into a more human-like cognitive mechanism.

4.2 Limitations

This study also faces with several limitations, as it represents only an initial step toward establishing such a framework. As Anderson [25] emphasizes, cognition is inherently complex, and no single model can fully capture this complexity. Nevertheless, the incremental development of unified frameworks remains essential. Similarly, design cognition is a highly complex phenomenon. At this stage, we employed ACT-R and integrated it with SMS by enriching its epistemological grounding; however, further refinement through exploratory and empirical studies is necessary.

With respect to SMS, the emotional dimensions of autobiographical memory were not examined in depth and were only briefly addressed here. While the retrieval of such memories may support designers' well-being and motivation due to their vivid sensory-perceptual qualities, it may also evoke distressing or traumatic content that could negatively affect emotional states, thereby raising ethical considerations. For this reason, any application of such a pathway in design practice should be strictly voluntary.

Moreover, given the study's methodological choices and limited scope, it does not present experimental data on design processes but instead offers an analytical overview based on the reflections of a single architect. Accordingly, the study supports the proposed framework, highlights several anticipated cognitive mechanisms, and demonstrates its potential applicability, rather than providing empirical refinement. We also acknowledge that reflective accounts may be unreliable, as individuals selectively and continuously reconstruct their memories over time, guided by personal beliefs.

4.3 Future Directions

Future research with a similar purpose could employ the proposed framework across a broader set of architectural case studies or protocol-based design studies. Such applications would help establish the framework's analytical robustness and offer deeper insights into how autobiographical memory shapes design reasoning. In design education, these studies may inform pedagogical approaches that purposefully encourage the use of autobiographical memories—both as a motivational resource and as a cognitive strategy that enhances emotional engagement and personal relevance in early design learning. However, the ethical implications of inviting students to draw on personal memories must be taken seriously. Any pedagogical implementation should prioritise student autonomy, psychological well-being, and voluntary participation. Properly framed, these approaches could support the development of creative confidence and a more reflective design identity.

The foundational models underpinning the framework—ACT-R and SMS—also open avenues for interdisciplinary research, particularly in collaboration with neuroscience. Both models are compatible with the integration of large-scale neural measurable data, enabling studies that triangulate verbal protocols. Such studies would enrich emerging research on the neuroscience of the design process.

5 Conclusions

This paper argues that lived spatial experiences and designed worlds cannot be separated within the architectural context: Each design is meaningful only through its potential in the lived world. We therefore claim that autobiographical memory supports design reasoning by providing architects with access to personal experiences accumulated throughout their lives. To account for this, we proposed an adapted cognitive model that integrates autobiographical memory (SMS) within the ACT-R framework, situated in a constructivist epistemology, to the context of architectural design.

The case of Zumthor's Thinking Architecture supports this claim. His reflections reveal that architectural design is not grounded solely in technical or rational decisions,

but also in deeply personal memory structures. Sensory and affective episodes from childhood, places, and materials serve as reservoirs that shape design goals, evoke inner images, and ultimately transform into built form.

This study contributes to design research methodologically through the proposed framework by providing a systemic view for analysing the dynamic cognitive activity of architects, explicitly extending to personal memories. The framework can further be used to explore and inform design strategies through patterns of memory-based reasoning. In this direction, the study highlights the potential of autobiographical memory as a reflective cognitive resource in both architectural design practice and education, with implications for student motivation and well-being. The framework also bridges architecture theory and cognitive science, and opens a path toward future research informed by neuroscience.

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