Neuroscience and Architecture:
A Study of Housing for Seniors

by

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Dalhousie University is located in Mi'kmaq'i,
the ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

Contents

Abstract

This thesis focuses on the design of kitchen-dining spaces for autonomous to semi-autonomous seniors that addresses their neural needs, taking into consideration the declines that are occurring in the brain. Designers rarely employ neuroscience research to understand and improve health and well-being. In Quebec, spaces for seniors that are better adapted to their physical and mental abilities are urgently needed. Current senior housing models do not take into account their physiological and cognitive needs, nor do they provide much support to reduce the rate of decline.

Architecture can participate in stimulating areas, neural pathways and coping mechanisms occurring in the brain involved in everyday actions. Further, we can create housing environments that support the elderly, promote their quality of life, and reduce or prevent the effects of decline. Using phenomenology and embodiment to support neuroscience and architecture, a methodology is proposed to design a kitchen-dining space from an evidence-based perspective.

Acknowledgements

I would like to sincerely thank my thesis supervisor Ted Cavanagh for his guidance, feedback and suggestions in helping me overcome challenges. I also had the pleasure of working with James Forren as my thesis advisor and Brian Lilley as my tutor.

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Chapter 1: Introduction

People spend over 90% of their time in environments designed by architects (Goldhagen 2017, xvi). Yet, very rarely in architecture schools or continuing education programs do students or architects learn about how spaces affect our brains and bodies. Designers are often reticent to integrate other disciplines in their design strategies because they believe that it would inhibit their creative process and their ability to come up with solutions to design problems (Martin 2014). Neuroscience is key to be able to create spaces that are adapted to their users, rather than basing the design process solely on intuition and built works (Eberhard 2009). The field of neuroscience incorporates both research on the brain as well as on the rest of the peripheral nervous system. I contend that by using new knowledge from different disciplines and becoming more informed about a population of users, designers expand the possibilities for design strategies that create environments with beneficial effects on their users.

The adequate adaptation of our spaces is even more important when we start talking about populations that require more support from the environment, such as the senior population. In Quebec, the population of seniors is increasing rapidly, and it is estimated that by 2030, about 25% of the population will be over 65 (Payeur, Azeredo, and Girard 2019). I argue that by creating spaces for autonomous or semi-autonomous seniors between the ages of 65 and 80 which directly target the declines that occur in the brain, we can promote brain and body health, and thus a better quality of life that will last longer. The current models for senior residences (also called retirement homes) do not incorporate knowledge about the aging brain and, therefore, should be rethought. They are built to provide shelter and a home for a brief period instead of supporting life activities and promoting the health and well-being of their residents. They are temporary solutions to try to deal with a significant loss in autonomy that has occurred in the senior (Armstrong 2009). The new spaces created using knowledge offered by neuroscience would be preventative: the environment itself could provide increased support to seniors for their daily activities and reduce many other kinds of issues that arise with aging, such as a diminished sense of worth and place in society (George et al. 2015). An example of this might be increasing the lighting quality, thereby reducing the cognitive load needed to perform a given task. This would increase the attentional control that the senior could provide for that given task, providing a greater sense of autonomy. Through this support, the elderly would be able to maintain their autonomy for longer, leading to greater happiness and sense of accomplishment.

I propose an evidence-based design (EBD) approach using current neuroscience research as the basis for the design strategies proposed. EBD acknowledges that other disciplines have relevant knowledge and can provide input that can help designs become meaningful and responsive to the needs of the users (Sailer et al. 2009). Through an iterative approach, each phase of the design is conceptualized through the lens of other fields of study and analysed using an innovative, rigorous and precise methodology that seeks to minimize the bias in the judgement of the designer. Tools such as sunlight studies using modeling software were used when necessary to provide accurate representations of realistic conditions.

Chapter 2 serves as the introduction into neuroscience, and the interdisciplinary field of neuroarchitecture, which can be defined as the application of neuroscience in the context of architecture (Higuera-Trujillo, Llinares, and Macagno 2021). It looks at understanding the effects of built environment on the cognition and physiology of the users. It provides the basis for the design framework and explains what is meant by an evidence-based methodology in architectural design.

In Chapter 3 EBD using neuroscience data is brought in to drive design strategies of kitchen-dining areas for seniors. This chapter also introduces the design strategies using neuroarchitectural features (NAF) and highlights the current limitations of the information in neuroscience.

Chapter 4 reflects on the fields of phenomenology and embodiment. It presents the role that these perspectives can play in supporting neuroscience research in providing a design strategy for housing for the elderly. It includes an example of the use of phenomenology in aiding to bridge the gap between neuroscience and architecture through analysis of experience of space.

Chapter 5 returns to the first iteration of the designs proposed and analyzes it through the lenses of phenomenology and embodiment to extract observations about the architecture that was designed and how it should be improved. It integrates these findings into a second iteration, where the full impact that architecture can have on our brains and bodies, and the power of architecture as a tool to support neuroscience is translated.

The concluding chapter reflects on this process of design, dividing it into two themes, the field of neuroscience in architecture and the field of architecture in neuroscience.

It opens a path towards future thoughts on the intersection of neuroscience and architecture, and the way each can influence the other. This design aims to test the systematic use of neuroscience research in the process of architectural design and how this process can offer better-adapted homes for seniors in Quebec. The kitchen-dining area is the testing ground for the methodology in the context of private spaces. By expanding the methodology studied in this thesis, guidelines can be developed for entire building housing models for the senior population of Quebec.

Chapter 2: The Aging Brain and the Environment

Attentional Control and the Brain

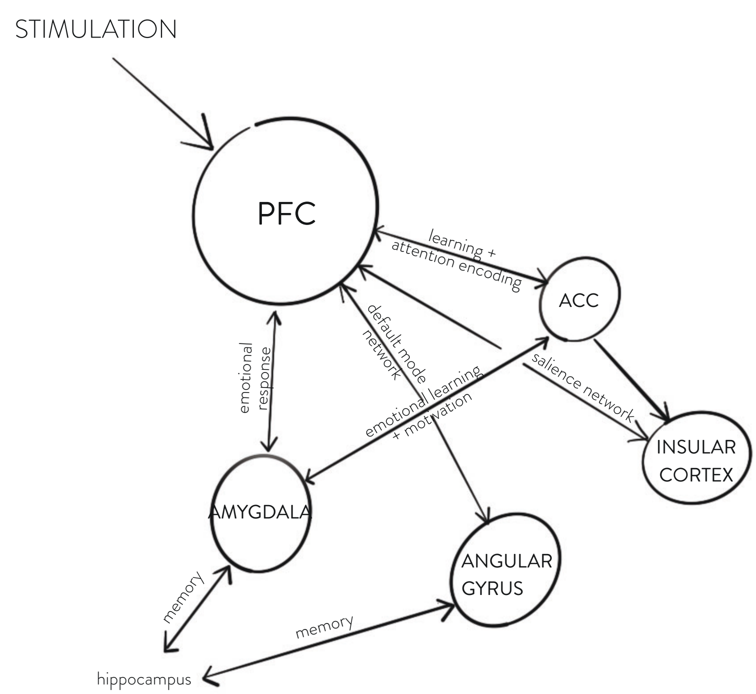
Neuroscience research seeks to understand how we react and act in the world around us. As we age, there are multiple elements of our nervous system that tend to decline, both in the central nervous system (the brain) and the peripheral nervous system. One of the main functions that is affected by the decline is the ability to pay attention in order to engage in complex cognitive behaviours, goal-oriented behaviours (planning, problem-solving, cognitive flexibility, selection, initiation of actions, emotional regulating, context-specific behaviour initiation, decision-making), also called executive functions (Kandel 2000). Goal-oriented behaviours are those behaviours that usually require multiple steps to accomplish. These would include most of what a person must do during a day: walking, cooking, talking to others, reading, etc. One of the components to control these behaviours is attention.

Attention

Attention as defined by Lindsay is "the flexible control of limited computational resources" (Lindsay 2020, 1). In other words, it could be described as the ability to engage and interact with the world. It has also been described as being a spotlight shone on an element of the environment, thereby increasing its importance in the role it plays in our environment (saliency) (Craik and Salthouse 2008). Like the spotlight's beam, the role of attention and its control over behaviours is very narrow. The following paragraphs and chapter diverge from defining attention in this manner so as to express more accurately the necessity to focus on attentional control in the senior population.

Brain Areas and Functions

The prefrontal cortex (PFC) is an association area involved in the planning and regulation of executive functions. It is connected to various areas that send different components of information related to attentional control of these goal-oriented behaviours. Though the PFC is connected to many different areas, the focus in this research, relevant to architectural design, are the amygdala, the anterior cingulate cortex, the angular gyrus and the insular cortex (London 2020). Each of these connected areas is involved in different aspects of attentional control: emotional responses, emotional learning, spatial cognition, saliency, etc. They are also connected to one another, modulating signals and affecting the overall behavioural outcome. It is also worth



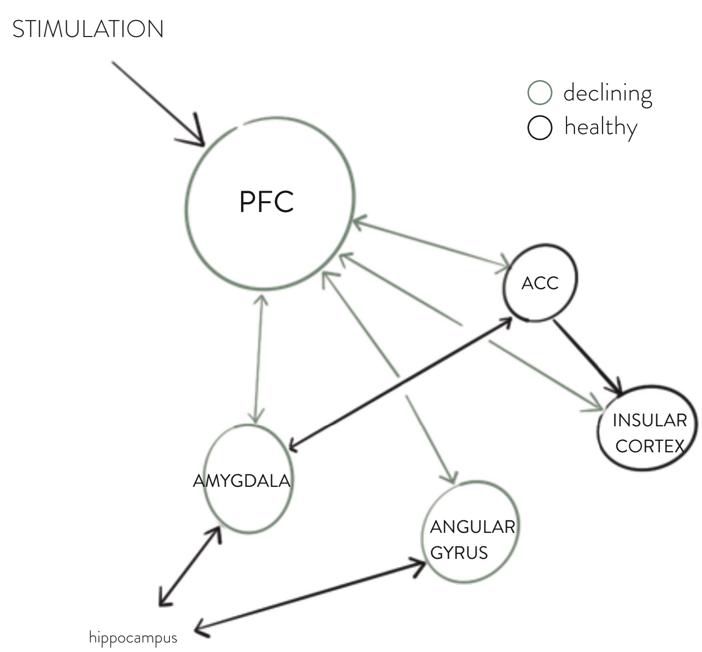
The above diagram shows the pathways and connections between the different relevant areas discussed in this paper. The types of information that is modulated from these pathways are noted.

mentioning that stimulation of some of these areas does not necessarily lead to an increase in attentional control; some lead to a decrease (inhibition of signal), and others have the opposite effect. The Appendix includes parts of a chapter of a previous work by the author and provides more detailed information on the function of the different areas mentioned above and their relationship with the PFC (London 2020).

The Aging Brain

Declining Brain Functions

The declines that occur as one ages can affect structural components, meaning a decrease in grey matter of the areas, or functional components, meaning a weakening of the pathways connecting the areas. Researchers have speculated on the process of the declining brain and three

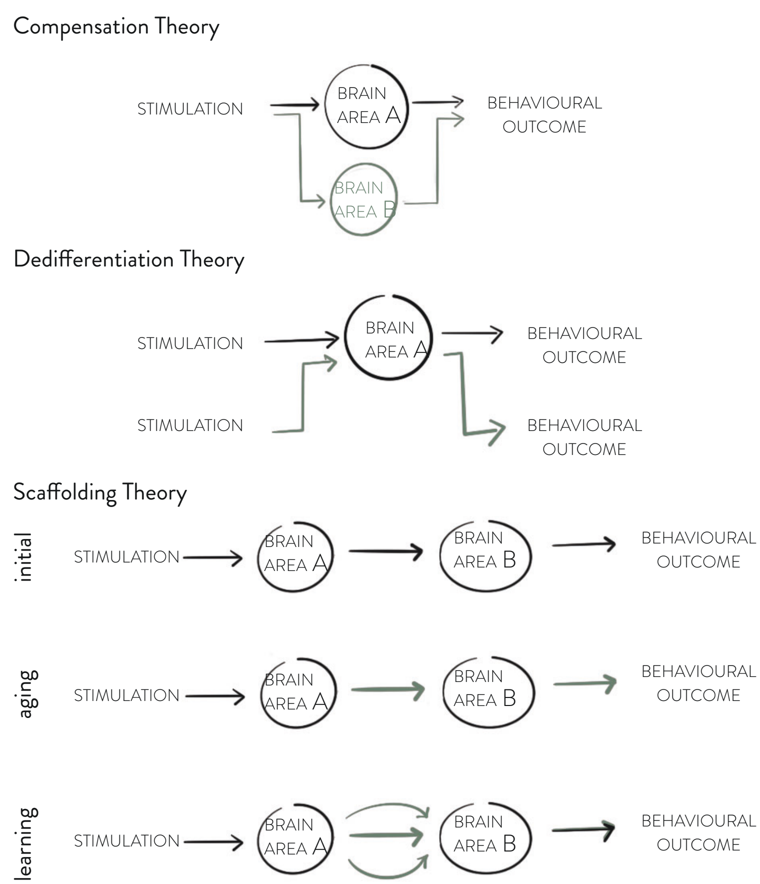


The above diagram shows the pathways and areas that are affected by aging. The declines are reflected in changes in cognition, behaviour and mobility. Reducing the rate of the decline of these areas can allow the seniors to be more independent, healthier and in control of their lives for a longer period of time.

theories stand out: the Inhibitory Deficit Hypothesis, the Salience Processing and the Goal-Maintenance Theory (London, 2020. [The Appendix describes these three theories]). These theories seek to explain how the declines in the brain affect the behaviour of seniors.

Coping Mechanisms

Our brain is not left to itself: as we are complex creatures, we have found ways of mitigating the effects of declines occurring in the brain. There are theories to explain these coping mechanisms that occur naturally but only three are mechanisms that could be influenced by exterior factors (like architectural design). The compensation theory explains the brain's mitigation to the decreased function of the PFC.



This diagram describes visually the coping mechanism theories in the aging brain.

In an aging brain, regions that are highly connected to the impaired area would be activated or stimulated by a stimulus that would have once only stimulated the impaired area (in this case the PFC). The stimulation of these other regions lessens the effect on the overall functioning of the organism (Cabeza et al. 2018). The dedifferentiation theory suggests that brain areas become less specific about what type of stimulus would activate them. Adjacent areas in aging brains would be activated by more different stimuli than in younger brains. There is a loss of specialized representation in the brain. This also seems to reduce the effects of the declining areas (Grady 2012). Finally, the scaffolding theory posits that the brain uses repeated stimulation of pathways to strengthen and create new pathways in the brain thus bypassing pathways that have weakened or that have been mostly severed (Park and Reuter-Lorenz 2009; Goh and Park 2009).

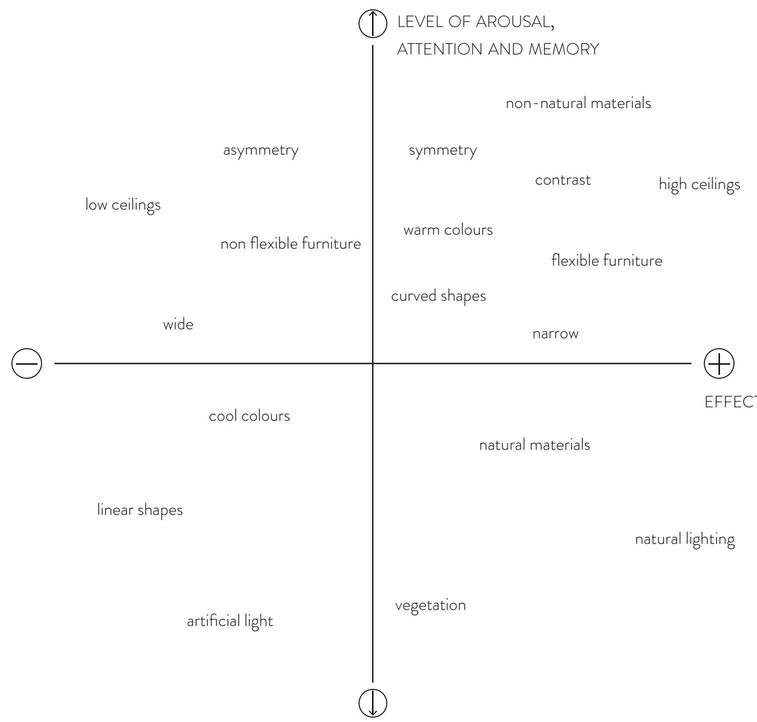
These three theories of coping, as well as the targeted areas and pathways that are involved in complex behaviour attentional control, are the key to this thesis's hypothesis. I hypothesize that if architects can find ways of stimulating these areas and pathways, their designs can naturally promote these coping mechanisms and support the brain to reduce the rate of decline in the brain. This improvement directly translates into better functioning in everyday life, thus providing a greater quality of life to seniors for a longer period.

Neuroarchitecture

Merging Neuroscience and Architecture

In the past twenty years, a field called neuroarchitecture has emerged. This field has as its goal to decipher the way a user experiences architecture and how it affects them, and in turn look at ways architects can integrate this information from neuroscience into architectural design (Wang et al. 2022). Based inherently in neuroscience, neuroarchitecture attempts to measure the effects of different spatial elements on brain responses and dynamics, ranging from the colour of walls and density of patterns to the size of openings, shapes of rooms and organization of spaces. Due to the difficulty of isolating these components in real-world environments, most research relies on 3D environments in virtual reality as a platform for studies. ANFA, the Academy of Neuroscience for Architecture, is an institution that has devoted itself to the overlapping study of brain dynamics and the built environment (Wang et al. 2022).

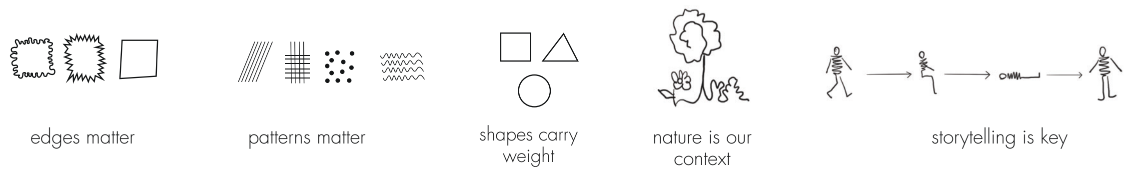
Results in neuroarchitecture research have begun to build knowledge about different architectural elements that can have positive effects on our brains. It must be mentioned that, because the architectural elements that were studies varied, as did the populations tested and the resulting brain recordings, it is difficult to generalize these results over all populations and every action performed in spaces in various conditions. The following diagram reviews some of the information that can be summarized from these different papers in a more visual and digestible manner (Karakas and Yildiz 2020; Higuera-Trujillo, Llinares, and Macagno 2021; Medhat Assem, Mohamed Khodeir, and Fathy 2023). The body of information is not very extensive and one of the major problems is that none of the studies directly targets seniors and their aging brains. Despite this, we can infer information from these studies and how the results may or may not change as the brain ages. The previous section (Declining Brain Functions) can provide a framework for these hypotheses as it explains some of the changes that occur in the aging brain. Using this information, we can therefore determine which elements could be beneficial in stimulating the brain and pathways to promote the coping mechanisms.



This diagram provides a summary of some of the information available in neuroarchitecture to this date. The sources used to create this diagram are the following papers: Karakas and Yildiz 2020; Higuera-Trujillo, Llinares, and Macagno 2021; Medhat Assem, Mohamed Khodeir, and Fathy 2023

Sussman’s Principles

Sussman and Hollander (2021) have hypothesized on five principles when looking at designing spaces for the health of the users: edges matter, patterns matter, shapes carry weight, nature is our context and storytelling is key. It is interesting to note that these principles do, in fact, encompass the different areas that have been researched and previously discussed. One caveat of these principles is that they are very general and tend to be elements that



The principles developed by Sussman and Hollander were based on various elements of our history and evolutionary past. “Edges matter” delves into the fact that people tend to follow and keep to edges of spaces, streets, public plazas. “Patterns matter” refers to our important reliance on vision as the central sense for orientation and survival. “Shapes carry weight” introduces the notion of symmetry and proportions of elements in space as key in our experiences and what we consider to be aesthetically pleasing. “Nature is our context” understands the importance of natural elements in our environments, bringing biophilia into the discussion of designing spaces. “Storytelling is key” refers to our ability to create scenarios and choose to act on them or not as a highly adaptive trait that only humans have.

architects already consider and integrate consciously or unconsciously when designing spaces. Additionally, though these principles could also be applied in the case of designing for the aging population, they consider vision to be the sole “experiencer” of space. There is no mention in the book of the other senses, or of the body being involved in the experience of space and the book relies heavily on an evolutionary perspective to explain our relationship with the built environment. I contend that this vision-centric view is reductionist, since humans experience space with all their senses and with their minds, and this is particularly true in the case of the aging population whose vision is often less good.

Eberhard’s Hypotheses

John Paul Eberhard, who was part of ANFA and one of the rare researchers that did some work focusing on seniors, hypothesized on different strategies or components in architectural design that could be beneficial to the aging population (2009). In his book *Brain Landscape: The Coexistence of Neuroscience and Architecture* (2009), he describes five of these hypotheses:

Diakonissestiftelsen, Copenhagen, August 2023. Eberhard’s Hypothesis 1 (2009). The flexibility of furnishing by the residents in the individual apartments stimulation of all kinds of memory pathways which in turn can support the mental capacities of the user and provide a strong sense of comfort and safety.

Diakonissestiftelsen, Copenhagen, August 2023. Eberhard's Hypothesis 2 (2009). High levels of lighting in the corridors reduce the cognitive load required for various actions and allows for room for additional beneficial stimulations such as social interactions.

House of Generations, Aarhus, August 2023. Eberhard's Hypothesis 3 (2009). The shape and dimensions of the entrance hall of the building affect the first experience that the resident has in the space affecting all following stimulations received from the building.

1. By allowing the flexibility to furnish your own spaces in a senior residence or nursing home you can support all different types of memories, including both procedural memories and working memories involved in complex behaviours and attentional control.

2. Providing high levels of illumination and increased contrast in a space allows for more social interactions which we know have beneficial effects on all spheres of cognition, including attentional control.

3. Dimensions and shapes of spaces can have a direct effect on sensory responses, and we can infer that these would also involve attentional control and mobility (and executive behaviours).

4. Repetition and redundant cuing in spaces can provide support for attention in wayfinding and reduce the cognitive load and reticence to move around in the building. This is particularly important in the case of populations who would have important cognitive deficits, which is not the target population in the case of this thesis.

5. Having specific areas for communal activities such as dining can promote socialization and habits which would have overall health benefits.

These hypotheses are a first concrete step in providing a framework for designing housing for the elderly, though these hypotheses remain to be thoroughly tested in real-world scenarios.

House of Generations, Aarhus, August 2023. Eberhard's Hypothesis 4 (2009). The hall is lined by repetitive lights support the wayfinding processes in the users and promote the mobility of the residents in the buildings.

House of Generations, Aarhus, August 2023. Eberhard's Hypothesis 5 (2009). The building has communal kitchens, on different floors to promote social interaction between the residents and create a sense of belonging to a community for the residents.

Evidence-Based Design

Evidence-Based Design (EBD) was first coined in architecture by Kirk Hamilton in 2003:

> Evidence-based design is a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project (Hamilton 2006, 31).

It was actually used before the term was coined; examples of this are environmental analyses of sites, "rapid ethnography" and material research for design of structures and envelopes. Introduced as an architectural equivalent for evidence-based medicine, EBD is different because it allows for more flexibility for the designer, both in the way to use the data and which data is used. It also allows for the individuality of each project, making the application of data a complex, variable process (Hamilton 2006). This thesis aims to use evidence-based research in neuroscience to drive the design.

In the previous sections of this chapter, I overviewed the important points in neuroscience of the aging brain and the target for this experimental design study. I also covered the current knowledge in neuroscience that can drive design, what I am coining neuroarchitectural features (NAF). To follow the principles of EBD, this information will be the basis for the development of an architectural design.

Chapter 3: Designing with Neuroscience

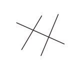
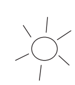
The Kitchen-Dining Space

The previous chapters and sections start to describe the evidence that will be used to provide an evidence-based design (EBD). They give architectural direction in various areas, such as proportions, colours, lighting, textures, etc. and hint at the creativity involved in the in-depth explorations of these features. Neuroscience can focus design into various aspects of space that promote or inhibit the stimulation of areas and pathways in the brain, reinforcing connections, and thus promoting coping mechanisms.

The kitchen-dining space is one of the most important centres of activity in the daily lives of the elderly. The kitchen-dining space of a housing unit is used for various goal-directed behaviours of everyday life such as cooking, cleaning, prepping, storing, etc. This research aims to facilitate these goal-directed behaviours by stimulating brain areas to reduce the cognitive load and increase attentional control. In parallel, I also consider the kitchen-dining area as a source for social interaction and show its potential for stimulating the body and mind. Possibilities for interactions include eating, talking and playing. These are an expression of the role of embodiment and movement in spaces as affordances for social stimulation and empathetic connections. Finally, there are higher cognitive actions that could be performed in this space which could promote additional stimulation of brain areas and pathways to support the coping mechanisms of the aging brain. Possible actions in this category are again eating, talking and playing, but could also include reading and mind-wandering. The goal in the kitchen-dining space is then to provide a space that can stimulate all three categories of actions simultaneously using the NAF. These are defined as physical aspects of space that are highlighted in the neuroscience research for their impact on the brain and the neurocognitive responses that they create.

Neuroarchitectural Features (NAF)

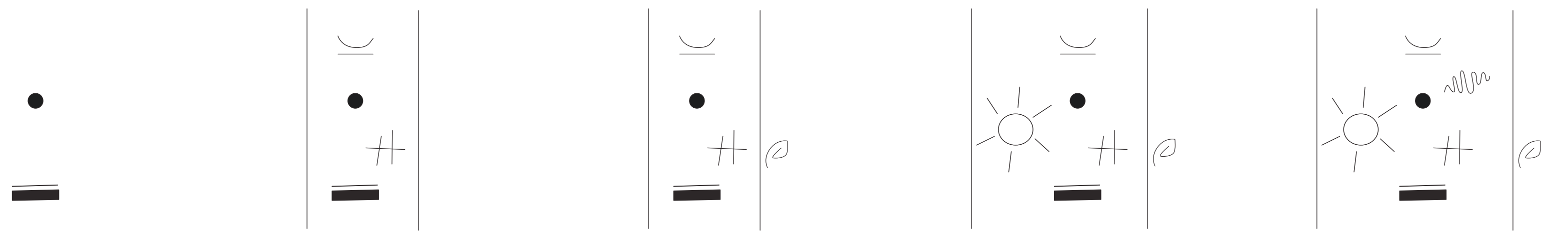
Each of the neuroarchitectural features (NAF) is intended to create a different response in the brain (stimulation), but the resulting effect on the behaviour may be similar. The features, therefore, may be involved differently when we discuss different actions that need support within the

Architectural Features	Neurocognitive Responses	Symbols
Asymettrical Forms	Higher cognition	
Cold-Hued Bright Colours	Improved selective at-tention and memory	
Curvilinear Shapes	Increase Activation in ACC, increased spatial information, working memory and attention control	
Narrow Spaces	Increased attention and memory	
Low Ceilings	Increased attention and memory	
Vegetation	Activation of spatial cognition (angu-lar gyrus) and increase of connection with PFC	
High Luminance	Decrease cognitive load and increase attentional control	
High Contrast	Increased selective attention	

Summary of neuroarchitecture research, the architectural features and their neurocognitive responses. The information was taken from various sources cited here (Medhat Assem, Mohamed Khodeir, and Fathy 2023; Karakas and Yildiz 2020; Banaei et al. 2017; Coburn et al. 2020; Bower, Tucker, and Enticott 2019; Hu and Roberts 2020) and the works cited in those sources. Each of the NAF was assigned a symbol that would be used in lieu of the full word to describe their expression in the following diagrams and studies.

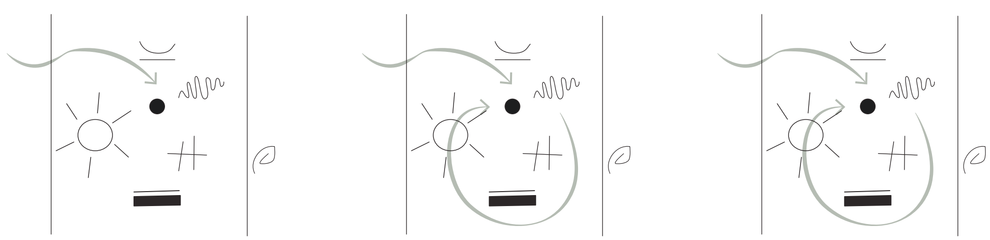
kitchen-dining area. For example, for one action, it may be important for a particular NAF be present right at the site of the action (the action area) to provide a high level of stimulation in a specific brain area, pathway or coping mechanism. In contrast, for another action this same NAF (and thus its corresponding stimulation) may not be optimal or may be better at lower levels and then the NAF could be situated further from the action area. As a result, before even considering the design of spaces for these actions and activities, we must understand the relationship between the features and each of the activities that we are trying to support within the space. The resulting diagrams create spatial relationships between the NAF and the actions. The NAF are positioned by considering the type of stimulation in the brain for that particular action with respect to attentional control. For example, for eating, it is important to reduce the cognitive load by providing a high luminance within the space of the action. At the periphery, we want to provide a contrast with surrounding spaces to provide support in selective attention and reduce distracting stimuli and the wandering mind.

Step 1: Determine the most relevant NAF for the specific action and the prefered relatioship with the area of action



1. For the action, increased need for selective attention. Adding contrast would isolate the action area from other actions areas.
2. Stimulation of memory pathways would promote motivation for the action of eating. Adding asymmetry, ceiling contrast and narrow spaces in direct proximity to the action area.
3. To avoid overstimulation and distractions, but still provide support of to direct attention towards the most salient information, the NAF of natural features should be present, smaller and in the peripehry of the action area.
4. For the action of eating, it is important to reduce the cognitive load, and you can do so by increasing the level of luminance directly at the area of action. The NAF of luminance is then at the area of action and very prominent.
5. As eating is a complex behaviour that necessitates working memory, learning and encoding of new stimuli, the stimulation of the ACC and the PFC through curvilinear features at the area of action would be recommended.

Step 2: Determine one would move to reach the action and perform the action



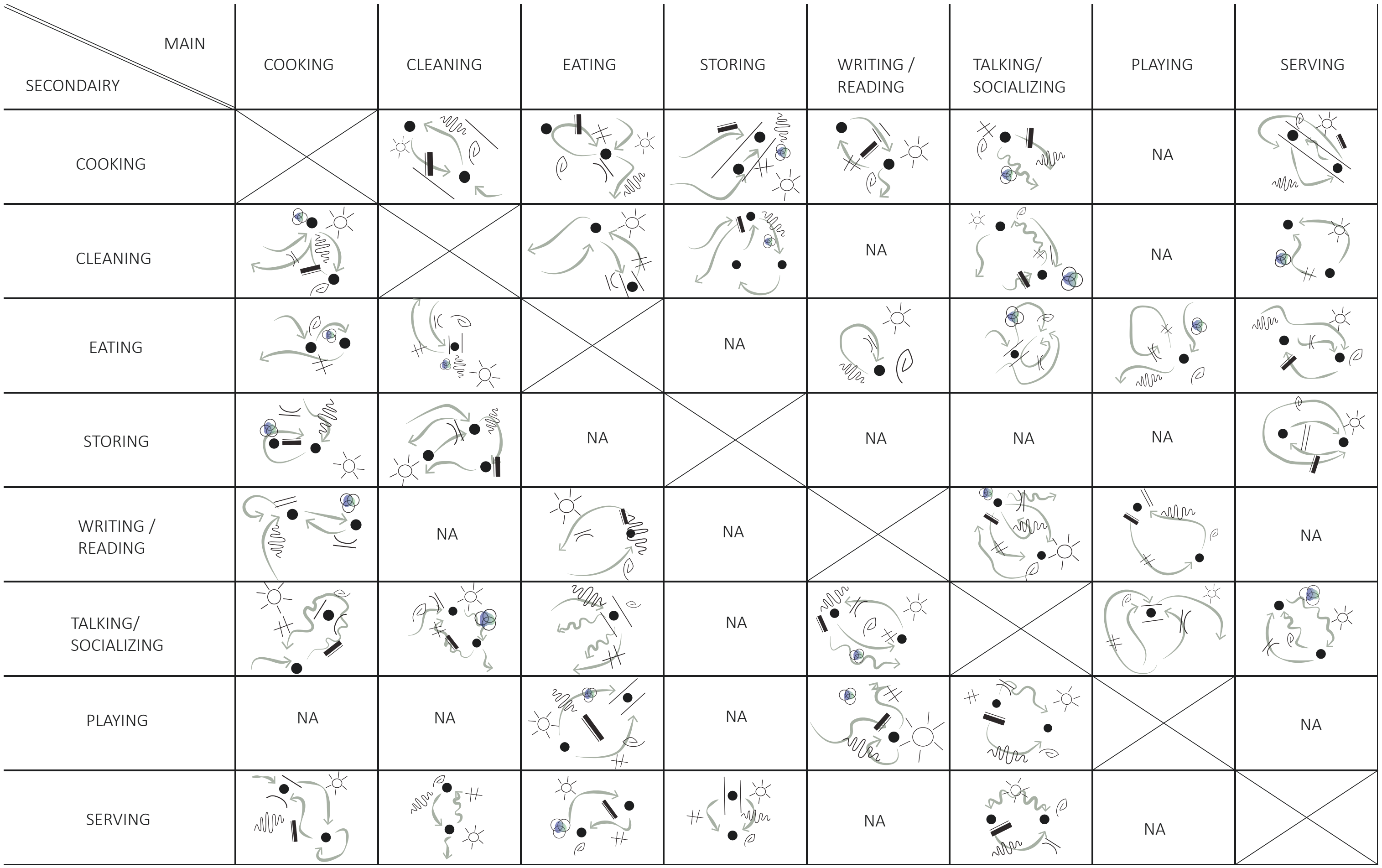
1. Entering in the area of action
2. Moving around on the chair or around the table

Example of a diagram that could be created when we look at one action in space and the NAF that could be expressed in the direct space of action and the periphery of the action performed. Here, we are looking at the action of eating.

There are very few instances in our lives where a person would be performing an isolated action, but rather a person tends to perform a series of actions: one action would be performed first followed by a second, a third, etc. To simplify the discussion in this experiment, we will be discussing sequences of two actions. The movements between the actions and their interactions (i.e., the way we go from performing one of the activities to another) would also have different needs for support from the NAF.

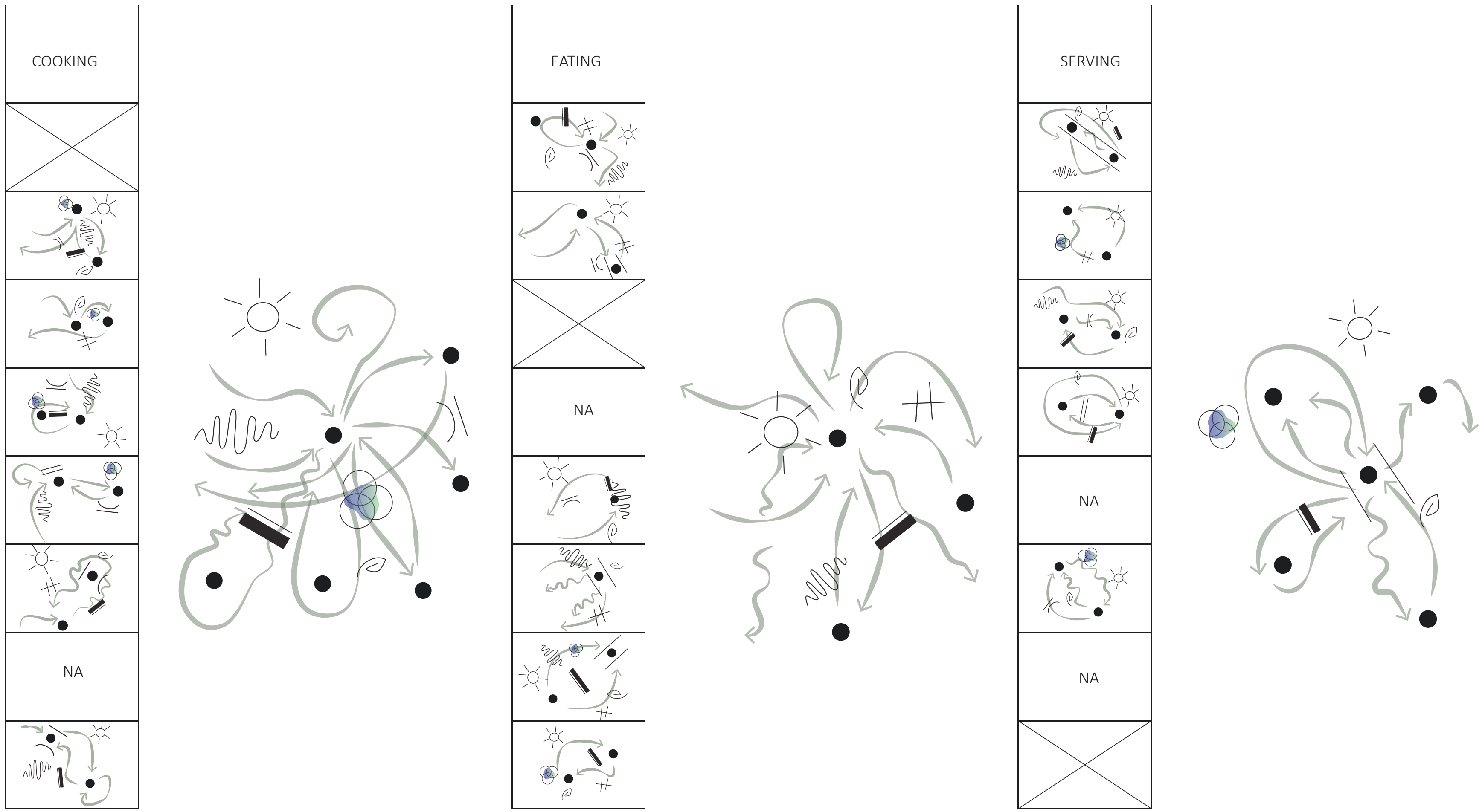
The evaluation of each action with respect to another action is a means to summarize information into a small set of diagrams. Each column of the matrix then becomes the relationship of one action with the NAF. Some of the NAF become more important as we analyze the columns of the matrix to provide one cohesive diagram for each of the actions. These are the features that become more important for the action and we can infer where they are situated with respect to the space where the action is performed.

As the matrix created demonstrates, the actions that would be performed in the kitchen-dining spaces are multiple and all have different relationships with the NAF that should be expressed as they are performed. To allow this process to continue, I simplify the discussion by only looking at three actions that are dominant when we discuss the kitchen-dining space: cooking, eating and serving (the action that would link both the other actions together as well as the spaces). The three that are extracted from the matrix and summarized are, therefore, those that the following sections will refer back to.



SECONDAIRY \ MAIN	COOKING	CLEANING	EATING	STORING	WRITING / READING	TALKING/ SOCIALIZING	PLAYING	SERVING
COOKING							NA	
CLEANING					NA		NA	
EATING				NA				
STORING			NA		NA	NA	NA	
WRITING / READING		NA		NA				NA
TALKING/ SOCIALIZING				NA				
PLAYING	NA	NA		NA				NA
SERVING					NA		NA	

This matrix presents the results of the diagrams that describe the relationship between the NAF and two actions in the space. Each of the diagrams in the matrix puts in relation a main action (the action that would be performed first) and the secondary action (the action that would be performed following the first). The neuroarchitectural support necessary is evaluated and expressed using the symbols that were previously defined. The matrix reflects the complexity of discussing the effect of space on the brain and behaviour, but also helps put into perspective the differences that can occur in the expression of the NAF with respect to the actions or activities that are performed in the space.



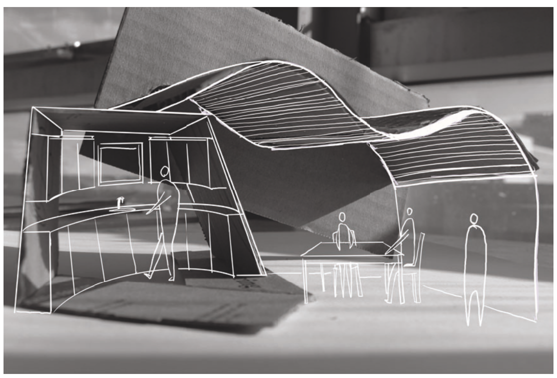
Each column of the matrix is extracted and summarized into one diagram. This diagram informs the final relationships between the action and the NAF for each of the actions in the space that needs to be created. Along with the diagram a verbal description is provided to give spatial understanding of this diagram. The summary diagrams are created by first highlighting the NAF that appear the most frequently. The NAF are then looked at in terms of how they tend to interact with the main action, whether they should be in direct contact with the action area or in the periphery. Finally, each diagram in the column also looks the size of each of the NAF which represents the level of stimulation that should be targeted in the area for that action

Physical Neuroarchitectural Features

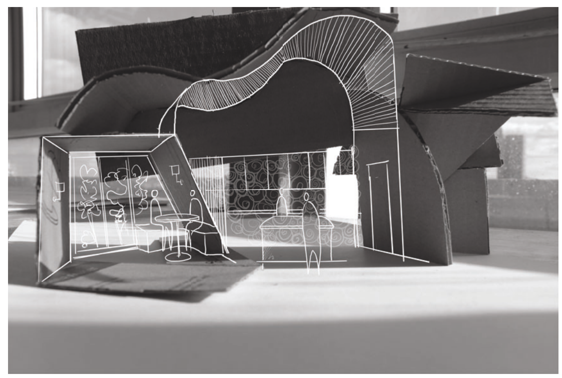
In parallel to the study of action and NAF, we must understand the expression of the NAF in the physical space, how they are expressed in their physical form. Using cardboard as a modeling material, I created a series of models that describe an example of the many forms that the NAF could take in the physical space. Though the models were initially intended to represent only one NAF each, the models show that isolating these NAF is very difficult and the models became representations of more than one NAF. The overall

The models are my representations of the NAF in the physical space. Photographs were taken of these models with a strong lighting to understand the effect of light and orientation on the physical space created from these NAF.

reflections from this step of modeling highlight the variety of physical expression of the NAF: structural, formal, textural, material, etc. The models were not made to scale, which allowed the flexibility to give them scale and orientation through photography. The photographs depicted both single models as well as combinations of models at multiple angles and sizes. These photographs were the starting point for the design of spaces, directly correlating the NAF to the kitchen-dining spaces.

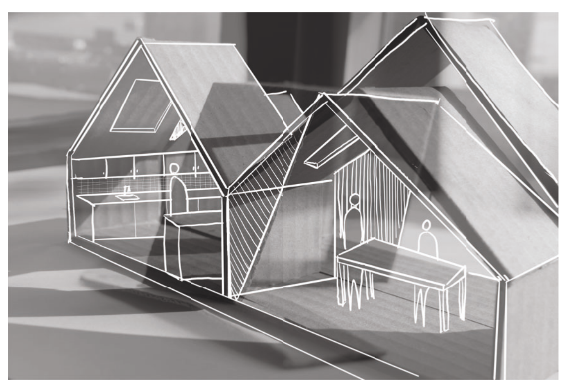


Variation 1



Variation 2

Variation 3



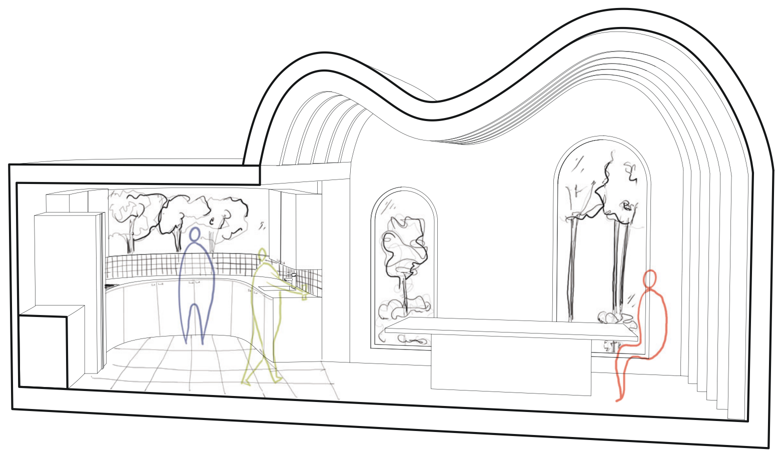
Variation 4

The images above combining photographs and sketch provide the backbone for the four following options developed for the kitchen-dining spaces according to neuroscience data. The photographs and sketches give a scale to the models, bring them in to architectural and livable spaces. Multiple sketches were tested with different model combinations, and four of those were chosen based on their potential to provide neuroarchitectural features necessary for the actions of cooking, serving and eating. Variation 1 combines models expressing the NAF of curved shapes, asymmetric and contrast. Variation 2 combines models expressing the NAF of contrast, curved shapes and contrast through ceiling height. Variation 3 combines models expressing the NAF of luminance, curves, ceiling heights and narrow spaces. Variation 4 combines models expressing the NAF of asymmetry, ceiling height, contrast and luminance.

These photographs served as the canvas for a series of four sketches that transform the non-scalar models into full-scale kitchen-dining spaces. The sketches overlap the physical expression of the NAF and the action-NAF correlations that were diagramed previously. Together they formed four different options representing the spaces derived from neuroscience data.

Iteration 1: Neuroscience as the Driving Force for Architectural Design

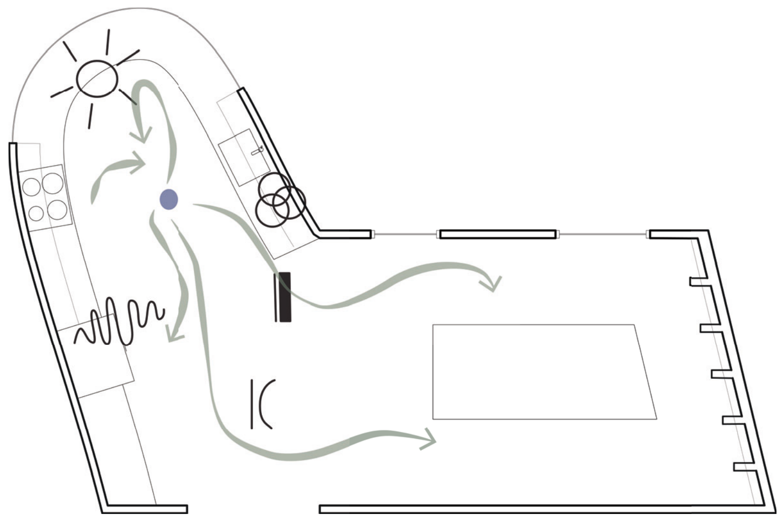
Variation 1



Sectional perspective of Variation 1

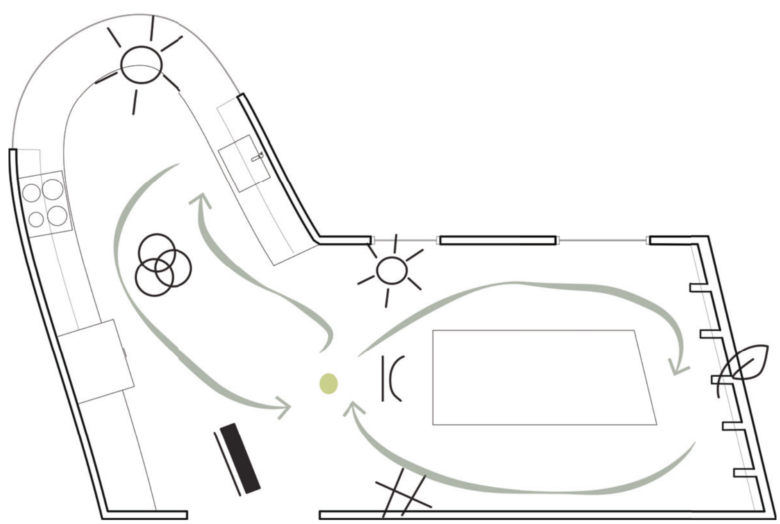
As you enter the space, there is a distinctive separation between two main elements, the floor plan lines and the different ceiling height and shape.

Cooking: The kitchen area has a large, curved window above the counter prep space, which serves different functions for the cooking action: a proximity of curvilinear features, a direct view towards the exterior bringing in a lot of luminance, and natural landscape into the cooking area. The colours within the kitchen create a sense of nature and landscape and the lack of ornament provides simplicity in the expression of the NAF. As you are cooking, you would be facing with your back to the dining space, reducing the effect of contrast in the space and different ceiling heights.



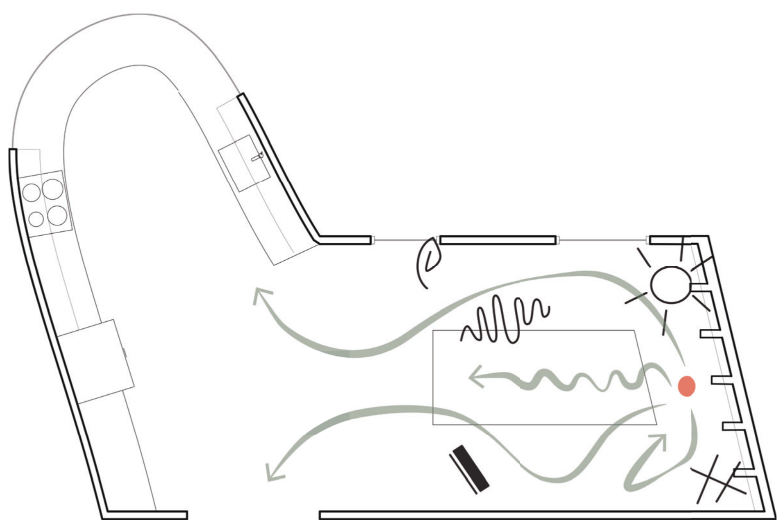
Relationship between the NAF and cooking action

Serving: As you walk towards the dining room, there is a stark contrast between the spaces, as the height and shape of ceilings change dramatically. There is also some asymmetry within the space as you enter with light entering



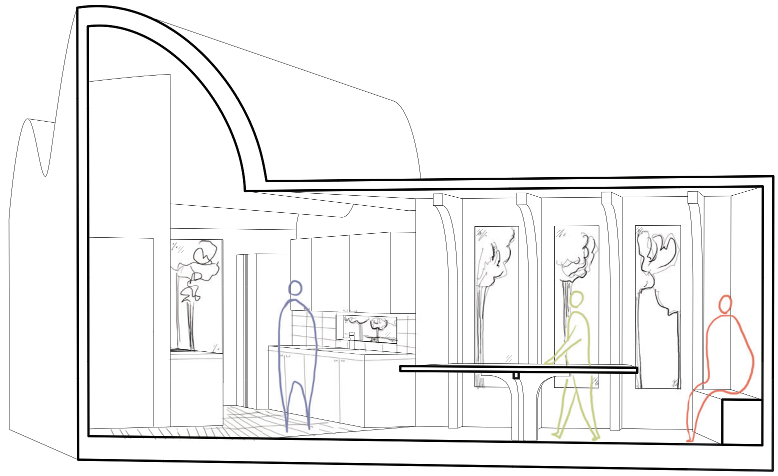
Relationship between the NAF and serving action from one side and an empty wall on the other. The wood structure of the dining area contrasts with the colours in the kitchen space. The natural material of the structure and the views towards the outside stimulate the brain due to the NAF of natural elements.

Eating: The height of the ceiling creates a very open area but can limit the sense of focus and concentration. The contrast between the kitchen and dining is evident through shape and dimensions of the spaces. The light entering the space and the large windows bring the outside in. This increased luminance reduces the cognitive load to perform the action. The view to the kitchen provides a direct contact between the two spaces. As you are physically close to the wood structure, the natural elements increase cognition and attention. The curves are present through the ceiling (which is quite far because of its height) and the arched windows.



Relationship between the NAF and eating action

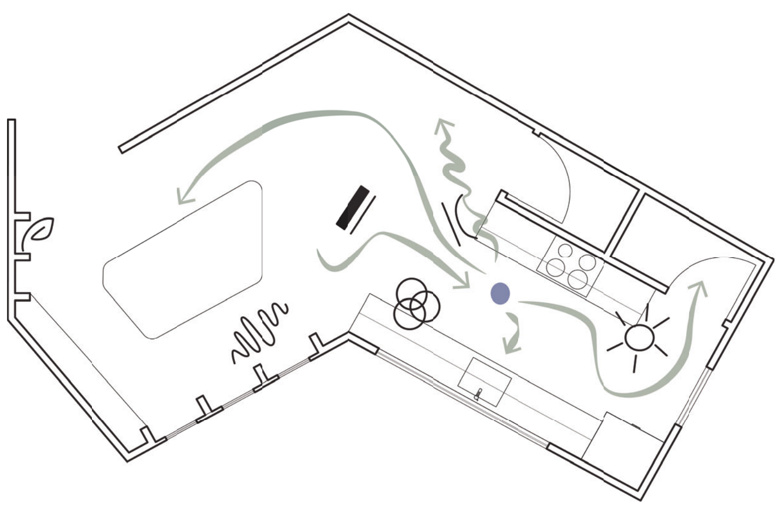
Variation 2



Sectional perspective of Variation 2

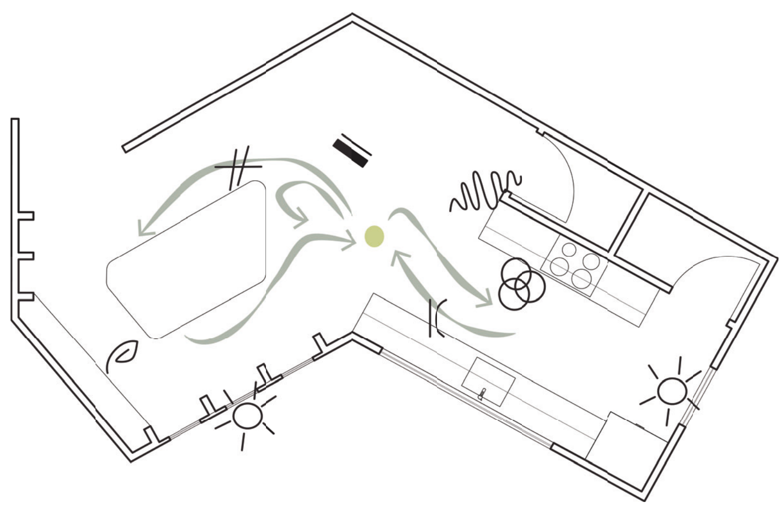
Rather than entering the space from the kitchen side, you enter the space into the dining area, in a low ceiling area with a wooden structure that resembles trees.

Cooking: The texture in the flooring distinguishes the kitchen from the dining area (allowing a contrast between the spaces). Light from the morning flows on the counter with the sink through in the afternoon providing more natural light for the task at hand. The differences of space are also delineated by the differences in ceiling heights from very



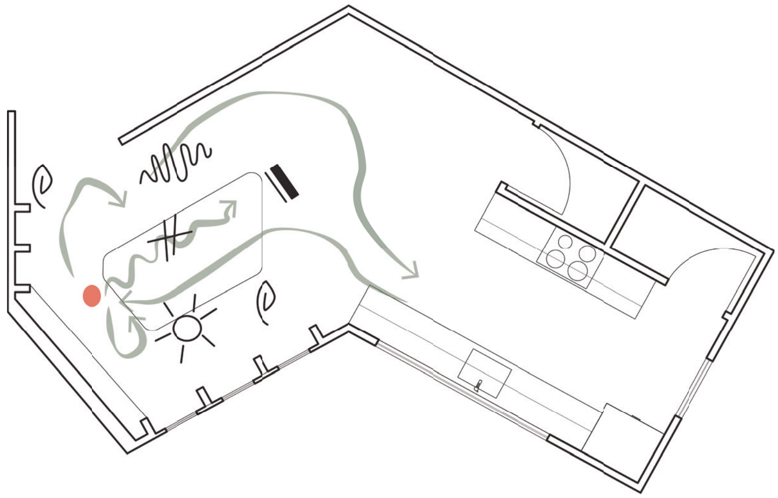
Relationship between the NAF and cooking action high in the kitchen to low in the dining area. Though the ceiling is curved, it is less present as you are doing the task, the focus being lower in the space. The narrowness of the kitchen also contrasts with the high ceiling as you are cooking.

Serving: As you go from the kitchen to the dining area, the different ceiling heights direct your movement to a lower, more intimate space for eating. The light enters the spaces differently in both spaces as the sun moves through during the day. The natural wooden features in the dining area and the large windows connect the action to the exterior surroundings and provide support from the natural elements (textures, views and shapes).



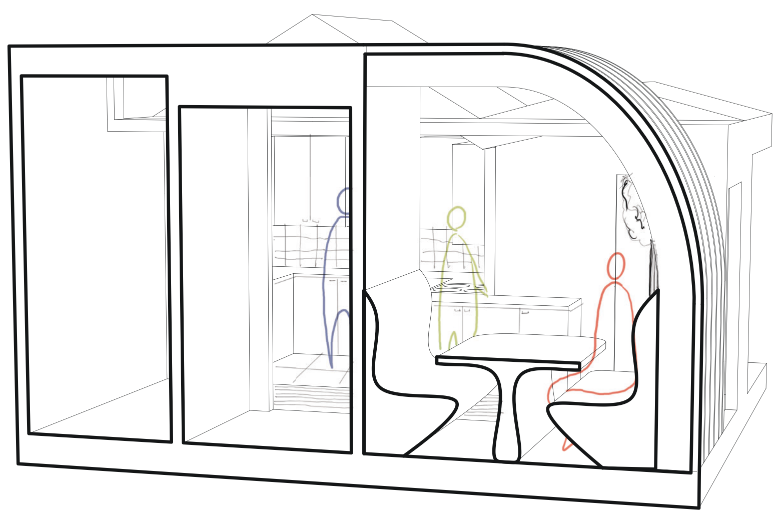
Relationship between the NAF and serving action

Eating: Light enters and flows onto the table, which is the focus for the action, increasing the luminance and reducing the cognitive load. Nature is all around with both the exterior views to the garden but also the very present wooden features. You get a glimpse of the kitchen space, but it is not overwhelming, reducing potentially distracting factors. The table's shape and the wooden structure bring in curvilinear elements in the area of the eating action in contact with the action of eating.



Relationship between the NAF and eating action

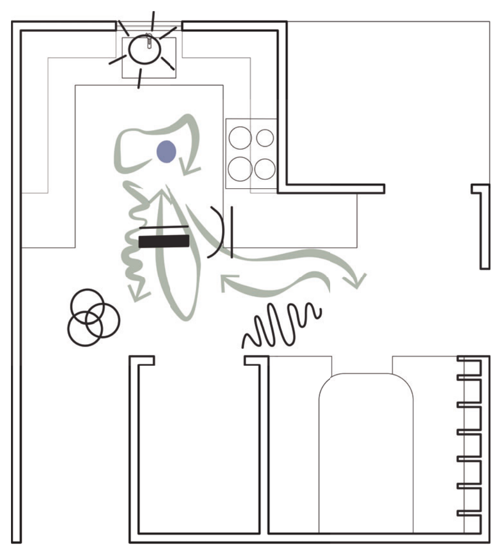
Variation 3



Sectional perspective of Variation 3

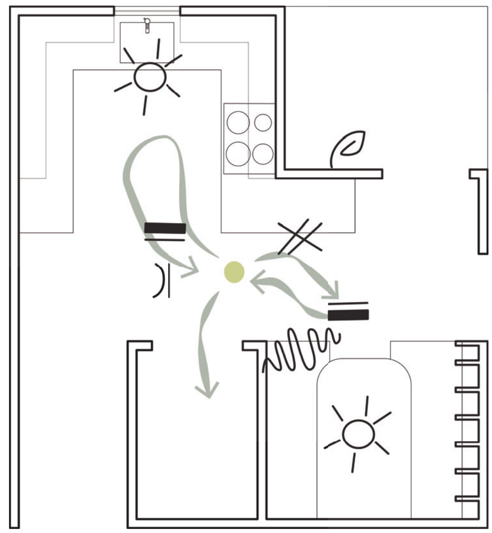
The kitchen-dining space is accessible through two entryways, which hints at a more central location for this space in the full layout of the unit. The space is more compartmentalized, which differs from the first and second variations.

Cooking: The space for cooking is well defined and because of the dimensions of the space, the movements that are required are limited, reducing the chances of distraction during the action. Indirect light from the window above the sink and the skylight bringing sun in provides high luminance to the space. The contrast created between the kitchen and circulation by changes in ceiling heights and textures isolates the action in its area. As you cook, you get a view towards the dining area structure, putting the NAF of curvilinear elements into the periphery for the action. Bright colours delineate the entrance to the space as well as the space for the cooking action (in the backsplash).



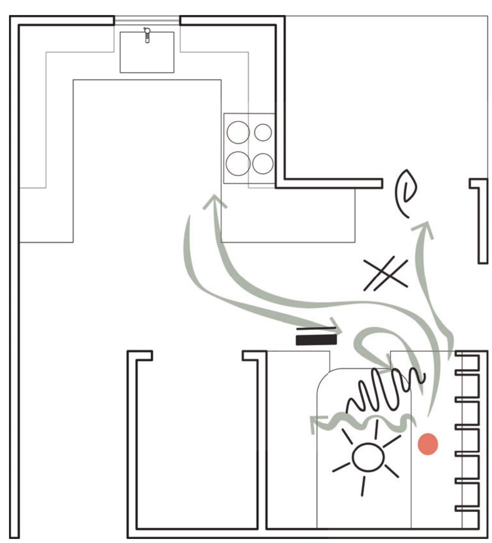
Relationship between the NAF and cooking action

Serving: The contrast that directs movement is made through the variety in ceiling shape and heights, as well as the type of lighting in the kitchen versus the dining area. The curved ceiling structure stands out both in its shape but also highlights the natural material of the wood. The ceilings, the flooring and the luminance of the space provide the user with support in orientating themselves during circulation between the areas and the serving action.



Relationship between the NAF and serving action

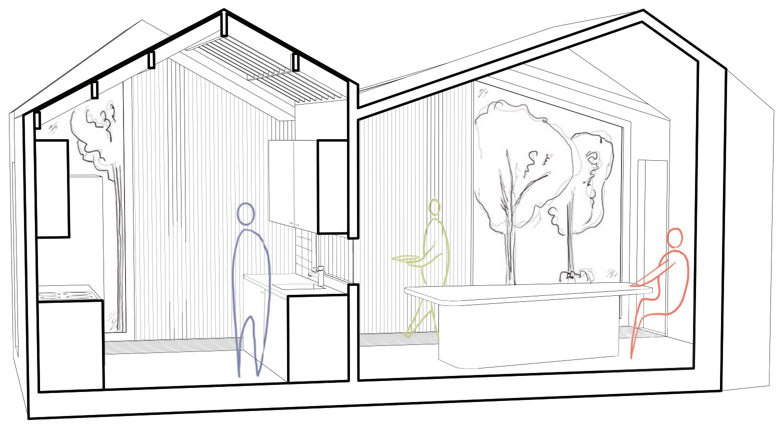
Eating: The most prominent NAF are the lighting (luminance) and the curvilinear wood structure that holds the glass panes which become the ceiling. The contrast of ceilings from dining to circulation to kitchen allow for the strict separation of the spaces. A large view towards the exterior connects the user to the natural landscape. This contrast can also hint at asymmetry in the space, experienced during the eating action.



Relationship between the NAF and eating action

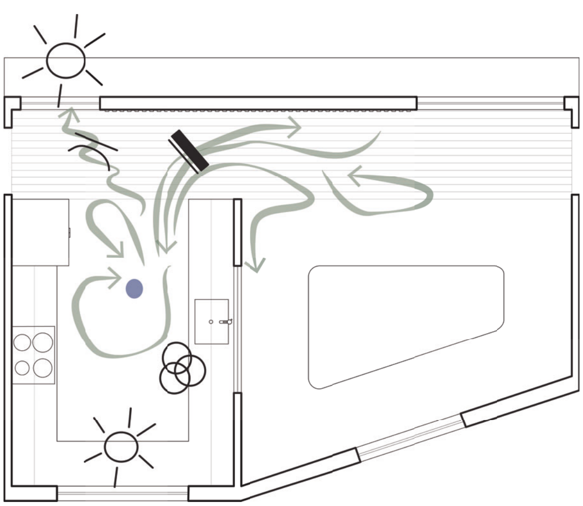
Variation 4

The entry to the kitchen-dining space is done from two ends. Rather than entering in either of the areas, the user enters into a circulation area. The angled ceilings divide the spaces as well as the wall that is apparent between the kitchen and the dining area.



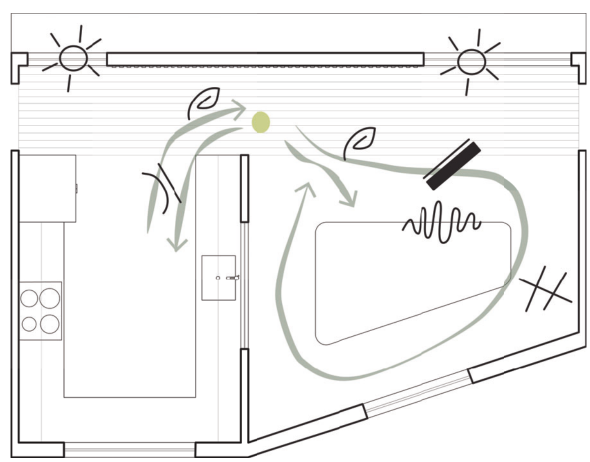
Sectional perspective of Variation 4

Cooking: Indirect and direct light from outside gives a high luminance to the cooking area. The contrast from the textures in the corridor and the colours in the kitchen separate the space. This concentrates the action in the kitchen. The views towards the exterior bring in the natural



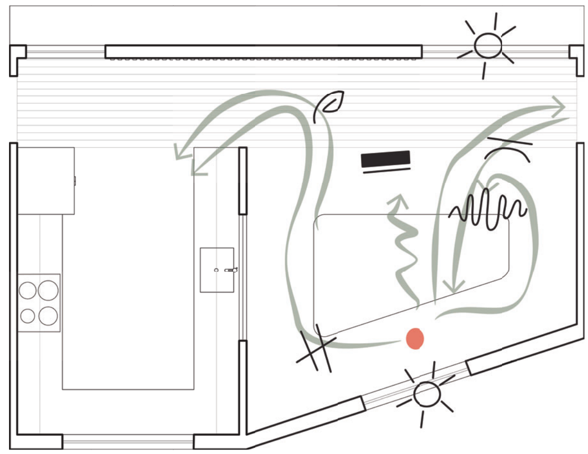
Relationship between the NAF and cooking action and urban landscape into the space. The window in the wall separating the kitchen and dining area gives a sense of understanding to the space, reducing the cognitive load as well and provides the stimulation for attentional control over the action.

Serving: Natural textures and views are present as you move from the kitchen to the dining area. Indirect light in the corridor provides for constant luminance and the direct light from both the spaces of the kitchen and dining also provide light that moves as the day goes by. A contrast is present between the circulation and the kitchen and the dining from the ceilings (shapes and variable heights), the textures and the level of luminance. The asymmetry is visible in the dining area and in the ceilings but is more present as you go towards the dining area and see an angled wall.



Relationship between the NAF and serving action

Eating: The only curvilinear feature is in the dining table. The wall coming inward and the table that follows the angle of the wall give the feeling of the asymmetry to the user while they eat. The different ceiling heights between the dining area and the circulation space divide the spaces and create a contrast between the area for eating and for serving. The shapes are similar, but they are treated differently. The textures from the circulation spaces radiate into the dining area. This is also emphasized by the views provided from the two windows.



Relationship between the NAF and eating action

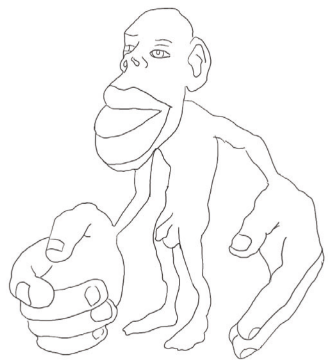
Limitations of Neuroscience Information to Date

From the descriptions of these variations, it is difficult to assess the quality of the architectural solution only through analysis of NAF and their effect on actions performed. The plans lack an overall cohesive expression. Neither the experience of space nor the way we inhabit it and move around it were taken into account when these options were developed and analyzed. In order to continue the analysis of these options, I turn to different fields to provide additional information to understand the gaps that remain after applying what neuroscience -- at least for the time being -- has to offer. Though neuroarchitecture is gaining momentum and the techniques for study and the technologies being developed will allow for further explorations, neuroscience alone cannot currently drive design since so few studies support the data previously mentioned. In the meantime, I consider other sources that could complement the neuroscience data to drive designs to support neurocognition and neural health in the aging population.

I turn to phenomenology and embodiment to give another perspective to our experience of space and allow more informed speculations on the effects of the built environment on our brains and bodies. By hypothesizing on the effects of experiences of spaces as defined by phenomenology on the aging brain, we can provide a more complete vocabulary for evidence-based design (EBD) using neuroscience.

Chapter 4: Phenomenology and Embodiment

Phenomenology of Perception



This image depicts the accurate representation of the size of the somatosensory cortex associated with each part of the body. This disproportionate account of the human body reminds us of the experiences that we can have of spaces, when elements in the built environment have more importance than others and take up more of the experience than others, colouring the event and experience in question.

Phenomenology seeks to understand the way we experience the world around us. First proposed by Husserl at the beginning of the 20th century, it has been evoked in literature in various ways and in different connected fields (Gallagher and Zahavi 2021). In recent years, people have started discussing neuroscience and phenomenology together in relation to the experience of space. Neuroscience and psychology are often seen as third-person perspectives on experience, since they break down the experience into components meant to explain our perception and our experience. Phenomenology is a first-person perspective as the experience is considered as a whole and as the final element that must be analyzed. Peri Bader states: “Phenomenology examines the structure of consciousness as experienced in the first-person point of view” (2015, 246). It is a study of the field of consciousness and experiences of the world. Phenomenology and neuroscience do not offer opposite or contradictory views of consciousness and experience of space, but rather complementary views. By integrating both the first-person and the third-person points of view, we can learn more about the way people perceive and experience the world.

Perceptual Experience

Phenomenology of perception became relevant in literature in the 1940s with the publishing of *La phénoménologie de la perception* by Merleau-Ponty (1976). This essay describes our perceptual experience as a more holistic experience than only describing the components that create it. It provides an in-depth understanding of the sensations and associations that form our own realities. This work, though, now close to 50 years old, is often referenced today to describe our perceptual experience. In the past ten years, we have seen this field of philosophy discussed in relation to scientific concepts, such as neuroscience's understanding of perception, specifically when we talk about our experience of social interactions and their relationship with neural dynamics.

Comparing these two images allows us to refer back to the human homunculus. The experience of space may not be the same as the sensorial perception. The emotional, bodily and atmospheric experience modifies and enhances the overall experience of the design features. The design proposal will inherently have larger consequences than only those of the physical space. Our own histories also affect these experiences as we associate information together in our brains and bodies in unique ways.

It is important to understand that the perspective of phenomenology is not only individual. Our conscious experience can be shared with others, as a collective experience (Fuchs 2013). The experience can also involve others, as your experience of another individual will be different when in different spaces. It is not because we talk about first-person point of view that we are talking only about individual points of view. The experience can involve physical elements but also non-physical ones such as social and cultural elements that are not expressed in the physical world.

Phenomenology of Attention

Phenomenology has attempted to describe attention more as a whole experience rather than a process that can be broken down. Arvidson's perspective describes attention as divided into three realms, the theme, the thematic context and the margin (Arvidson 2003). All three work together and constitute attention: none can be separated from the others. These components of attention are in a state of equilibrium and the equilibrium tends to change between the components, varying the state of the experience of attention in space. "Within and between the dimensions of theme,

Arvidson's fields of attention. The images visually express the theme (left), the thematic context (centre) and the margin (right) within an experience of space. The theme is described as the focal attention, the centre of the scene. The thematic context has relevance from the theme and other thematic context. The margin is presented with the theme and the thematic context, but it does not need to be relevant to the theme.

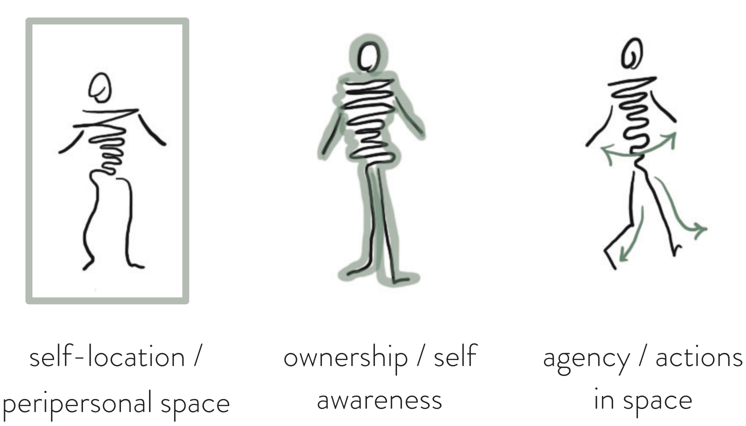
thematic context, and margin, attention is a transformation of presented content in dynamic tension with other content" (Arvidson 2003, 105). Attention is the process that allows us to assign meaning in the world. This new perspective of attention leads me to infer that we need to consider the space as a whole when designing for attentional control, restricting the design to individual details would lead to suboptimal results. That is not to say that details are not important but rather that combining these elements will enable the effects to be more pronounced. In other words, we could say that the sum of the elements provides more benefits than the individual elements themselves (Arvidson 2006). Though I do agree that a holistic view of experience can provide surprising insight into architectural design, I also think that the details of architectural design can be very important to provide a beneficial experience of space. The role of attention in the experience of space, in both quantity and quality, is crucial because our experience changes if more or less attention is placed upon something. The field of attention overlaps the field of consciousness as you are conscious of something if you were paying attention to it.

Embodiment

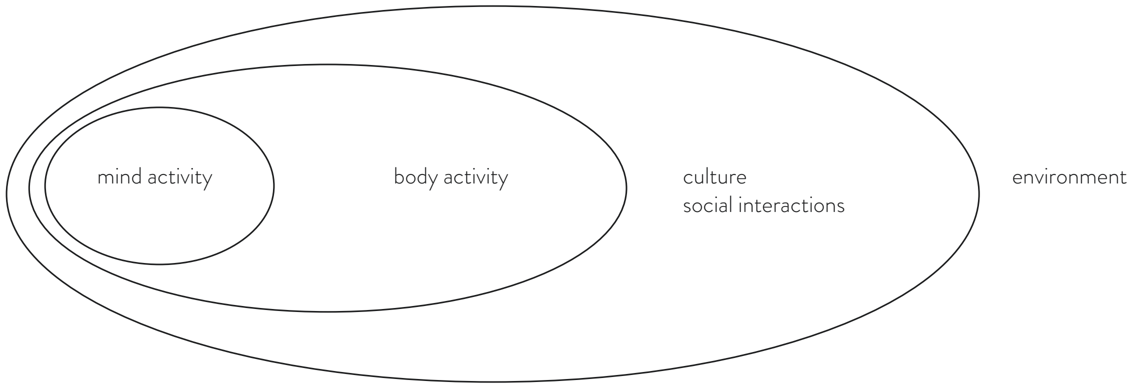
> Le corps est le véhicule de l'être au monde, et avoir un corps c'est pour un vivant se joindre à un milieu défini, se confondre avec certains projets et s'y engager continuellement.(Merleau-Ponty 1976, 97) [The body is the vehicle of being in the world, and having a body is, for a living creature, to be intervolved in a definite environment, to identify oneself with certain projects and be continually committed to them. Translated by Smith in Merleau-Ponty 2002, 94]

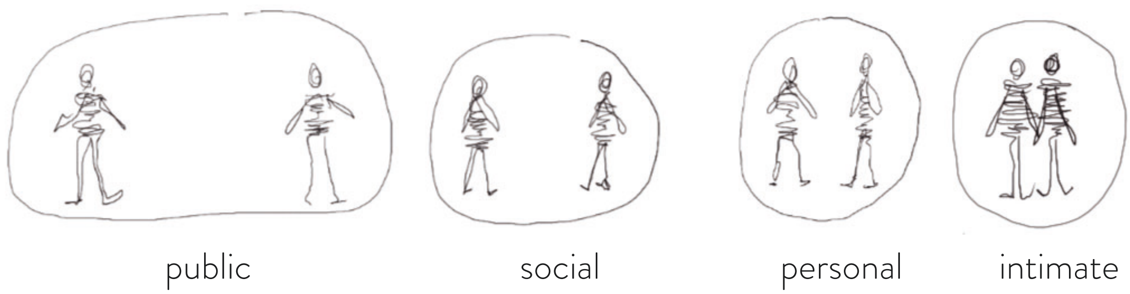
Embodied Space

When we experience spaces, we cannot reduce our experience to what we are seeing, touching, hearing, or feeling in our minds. We must consider our bodies as direct receptors for experience as well (Leitan and Chaffey 2014; Goldhagen 2017). Embodiment refers to the relationship between our bodies and the exterior environment (Robinson and Pallasmaa 2015). The experience of ourselves involves the active movement of our bodies within space and the physical space that our bodies take in the world. The role of the body in our experience of space is varied but we can all think of the time when the chair was so uncomfortable that regardless how much you tried, you could not focus on the professor in front of the classroom. The body becomes key to understanding the limitations of our attentional control on our behaviours (Borrett, Kelly, and Kwan 2000). In discussing the role of attention in experience of space, therefore, we must look at embodied attention. Embodied attention is the idea that the position of our body, as well as movements around it and spaces around it or peripersonal space, are involved in shaping our experience (D'Angelo 2020). Embodied attention creates meaning for our experiences which then also affects both experiences afterwards and past ones. It is unreasonable to separate bodily attention from attention because it is through the combination of the two that we create our full experience in space.



Understanding the space through our bodies and shaping experiences through actions and sequences of bodily movements.





Our bodies create a means to understand the world and others. This diagram expresses theories of embodied social cognition where the mind, the body and cultural and social interactions relate to our response to the built environment. The distance in space between two people will influence their experience. These ranges should be considered when designing spaces that aim at promoting different types of bodily interactions between two people.

Social Embodiment

Merleau-Ponty discusses the role of the body in social interactions (intercorporeality) and experience as well as the idea that our social interactions affect our experience of our built environment (1976, 406). As the built environment affords us movement, perceptions, sensations, the bodies of others with which we interact become vessels for these sensations as well. Our bodies and past experiences affect the current embodied social interaction. Experiential body understanding and social interactions are, therefore, one of the components that creates our experience of space (Lindblom 2015). The link between our bodies and others has been explored scientifically. Vittorio Gallese is considered by most neuroscientists the discoverer of "mirror neurons", neurons that are our way of embodying empathy (Gallese 2016). Empathy allows us to connect to others by "feeling" in our brains what they are feeling. When discussing our experience of the built environment, we cannot discard our social interactions within spaces, since they provide additional aspects of this experience that can mold our perception of our place in society. This is particularly important in the case of aging populations. For seniors, continuing to be part of society, having a sense of belonging and being relevant and useful colours their everyday lives. Social interactions, especially those they have with people who are not members of their family, provide this sense. These social interactions in later life have been studied to stimulate the brain in some of the same areas previously discussed, reinforcing the idea that stimulation of these areas increases the quality of cognitive functions and that the more social interactions there are the better the quality of the cognitive functions (Zhaoyang et al. 2018).

The Experience of Space

In architecture, Steven Holl, Juhani Pallasmaa, Alberto Perez-Gomez and others have used phenomenology as a way of analyzing architectural experience and the effect that space has on a person, their behaviour, movements and interactions ((Pallasmaa 2012; Robinson and Pallasmaa 2015; Bachelard and Hiéronimus 2020; Zumthor, Oberli-Turner, and Schelbert 2015; Holl 1998). These authors have described phenomenology of architecture in different ways, but they all see it as atmosphere. Each integrates haptics, light, textures, shapes and proportions used to create atmospheres and to change users' experiences of spaces. An idea common to all these authors is that users of a space first experience the atmosphere before being able to decipher the architectural details within the space. Though each architectural detail can be analyzed and deconstructed, the full perception of the space, the one that allows a real experience of it, cannot ultimately be divided into geometries, details and sensations. Architecture transcends perception of a physical space and seeks to stimulate inner and outer perceptions of space to provide a unified experience of the space. Holl, Pallasmaa and Pérez Gómez bring up key aspects that are relevant when discussing emotional connections to spaces and the experience of space to shape everyday life in their work *Questions of Perception*(2006). They fail to mention, however, the role of social interactions in spaces, giving an additional dimension to the experience and atmosphere of the space. This thesis seeks to combine all these concepts to support neuroscience research about the aging brain. The role of phenomenology and embodiment is to provide additional insight to frame the design strategy and conclude with a space and experience of space that works, both from a neuroscience perspective and an architectural perspective.

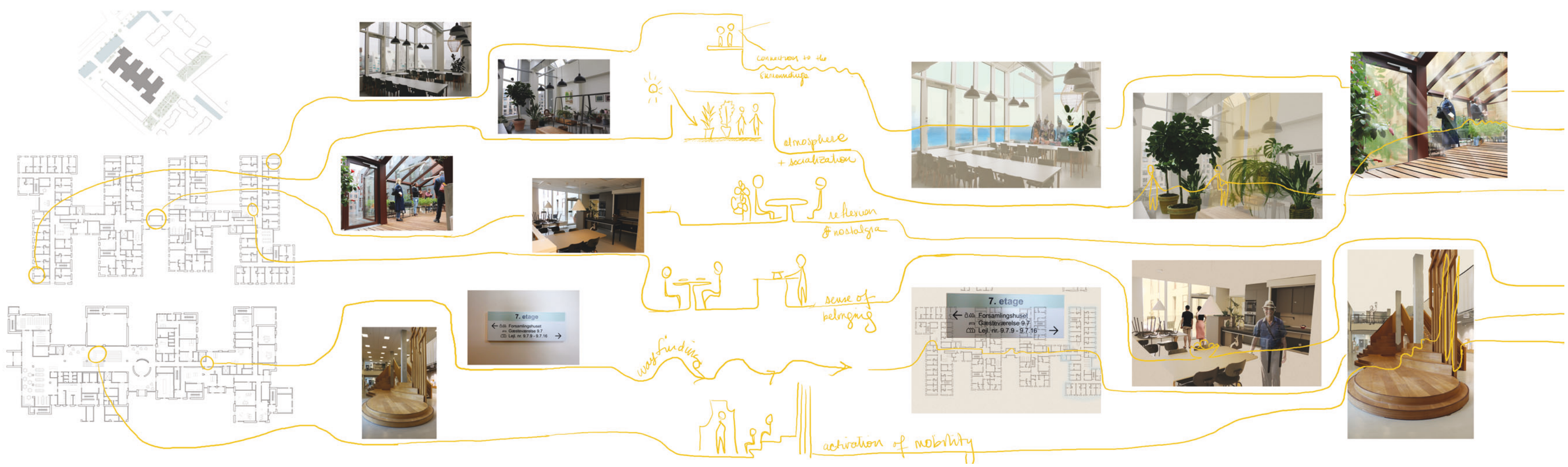
Rossetti Scholarship Research

A Case for the Link Between Phenomenology, Embodiment and Neuroscience

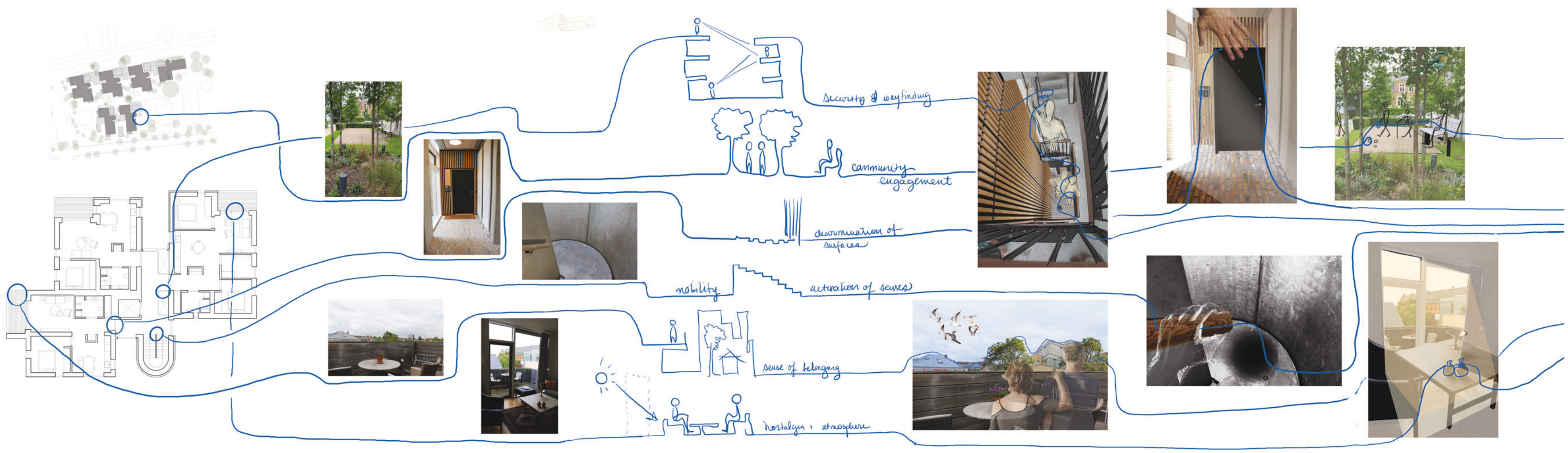
The fields of phenomenology and embodiment not only provide an additional method of viewing the experience we have of spaces, but they also emphasize the role of social interactions in our experience of space. To test the benefits of using phenomenology and embodiment in the methodology of design, I analyzed two senior housing models in Denmark. Both projects are innovative models for senior residences that have been mostly successful in their approach of providing support and an adapted space for their users. The success has been reported by the residents, the clients and the building managers of the different projects. Neither of these projects, however, involved neuroscientists or psychologists in the design process. .

The architects were interviewed to understand their intentions in the design strategies employed. They had also talked previously to some of the residents to get their input on the use of the spaces and to support or oppose the original intent for the architectural features. The projects were visited and photographs were taken along with the notes about the spaces and how the residents have reacted to them (frequency of use, the report of emotional reactions and functional analysis). Using a bottom-up process, I delved into describing the experience of space through diagrams and collage, mimicking the idea of the human homunculus. These descriptions were explored through the neuroscientific lens, extracting elements of the built environment and design strategies to see how these could have stimulated areas of the brain involved in executive functions and attentional control for the different tasks and goal-directed behaviours that were meant to be performed in these spaces. My approach was, therefore, to analyze the experience of spaces in the buildings and hypothesize on the effects they are having on the brain areas and pathways previously discussed. This was done to understand the reasons for the success of the spaces. The resulting analysis provides an interesting lens for the study of the spaces, using an approach that links the actual experience of spaces from the users' perspective with the neural correlates and stimulations that would be occurring.

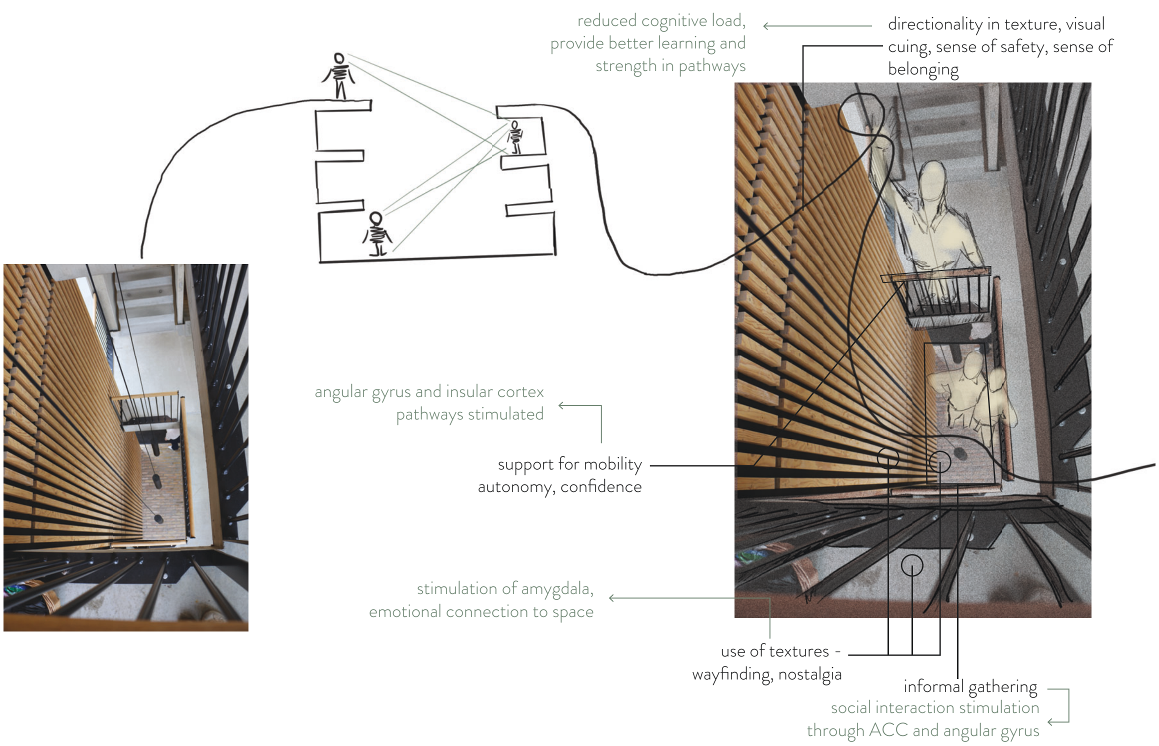
It is also used to support the approach I propose, that using phenomenology and embodiment we can further design and create spaces that work and have an architectural depth and neuroscience foundation. The following chapter seeks to integrate knowledge derived from the phenomenology and embodiment literature to analyze the first iteration's variations and underscore architecture as the driving force for neuroscience stimulation.

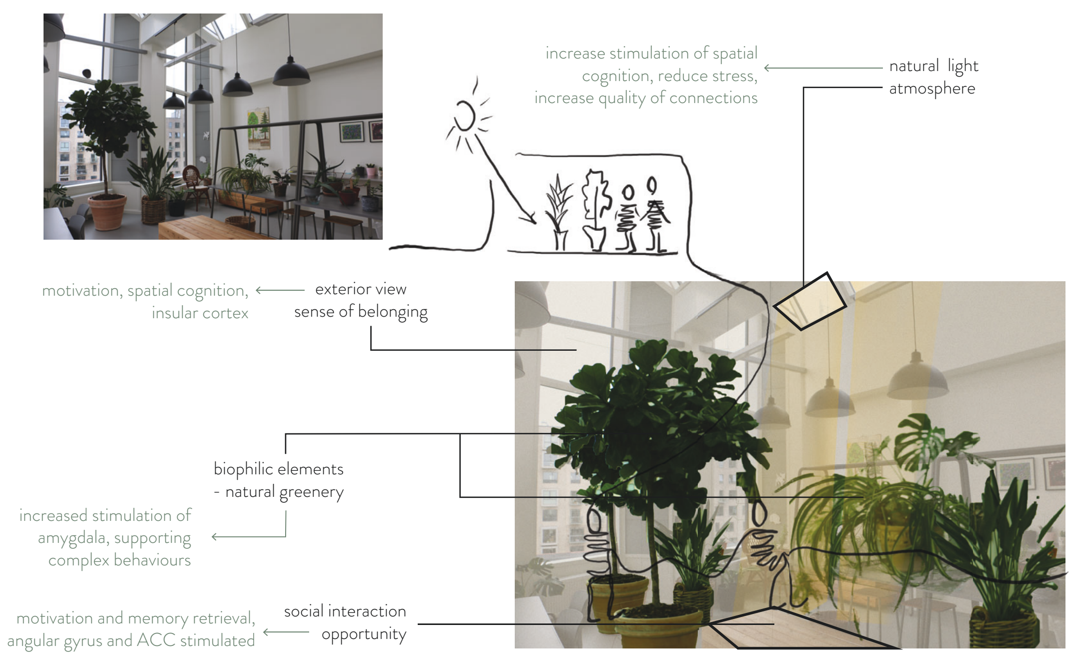


Project 1 House of Generation, Photos August 2023. (Location: Aarhus, Architect: Rum, Date of Completion: 2020) Initially designed for a competition, this multiresidential, multigenerational building houses a daycare, a cafe, senior apartments, nursing home units, family apartments, youth apartments and mixed population shared apartments. The residents of the project have accepted to have smaller private spaces in exchange for a variety of semi-public spaces, such as communal kitchens, a gym, a greenhouse, coworking spaces, a workshop as well as multiuse rooms, The tight site reduced the possibilities for exterior spaces on the ground floor, but each of the common areas have a direct access to exterior terrasses and balconies. The units have juliets with a full-sized window for connections to the exterior



Project 2 Diakonissestiftelsen, Photos August 2023. (Location: Copenhagen, Architect: Vandkunsten, Date of Completion: 2018) The project was designed collaboratively with the client and the future tenants. There are six buildings, housing between five and seven units each over three levels. Each building has similar materiality, both exterior and interior. The residents have access to a communal kitchen as well as the gardens with covered bicycle parking, boules areas and a fountain. The main innovation is the adaptability of the units as the seniors age to provide more support: as mobility becomes reduced, for example, openings in walls can be modified to accommodate wheelchairs, and support bars can be added. The project is located in the centre of a bustling neighbourhood, allowing the residents to participate in a variety of activities in the city.





Photos taken August 2023. The two examples shown are possible analyses of experiences of space and their neural correlates from the previous projects. These allow us to speculate on the reasons the spaces are successful in the senior housing projects.

Chapter 5: Architecture for the Benefit of Neuroscience

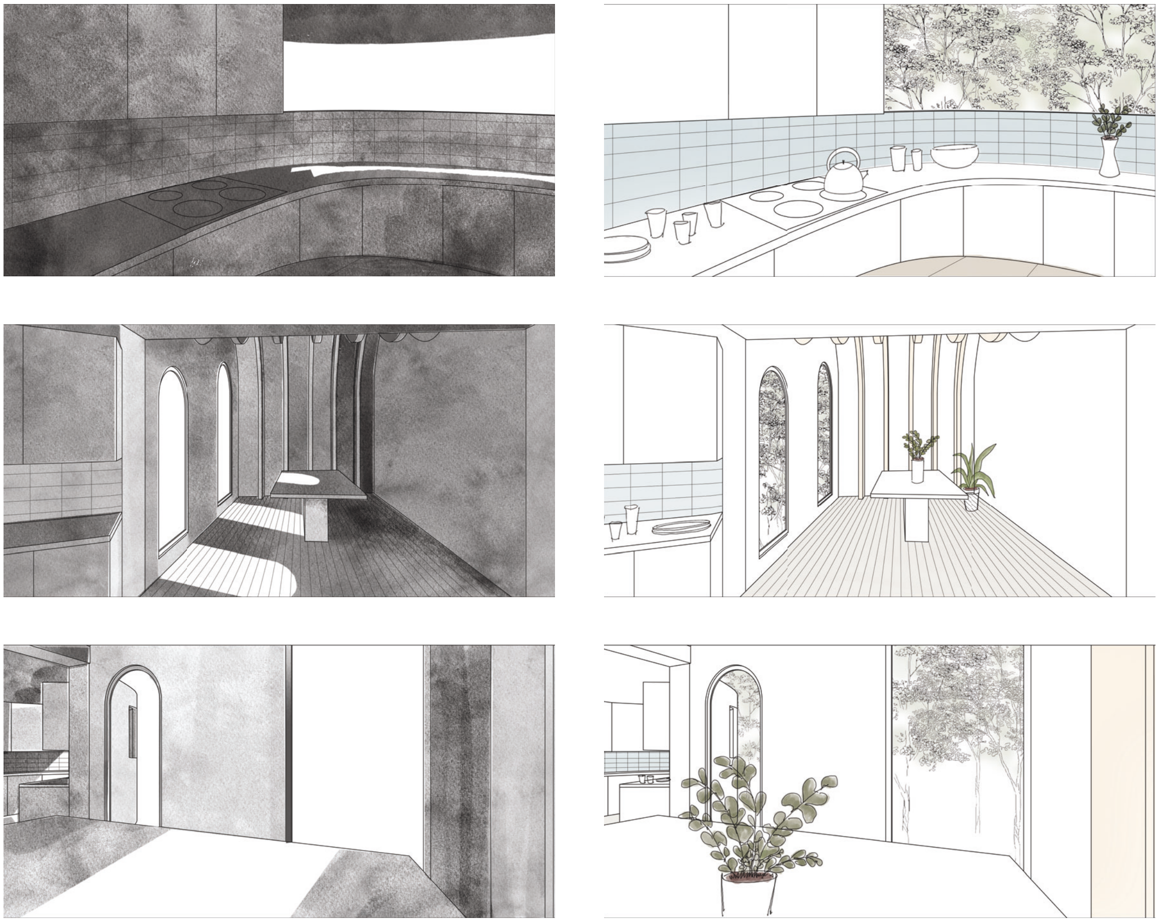
Phenomenology and embodiment teach us that there are other ways of studying space that can in turn impact our design of such spaces. This section analyzes the first iteration variations through these lenses and concludes with overall observations about the architectural spaces created to fuel a second iteration of the kitchen-dining space. In the second iteration, architecture plays a stronger role in providing neuroscience with the tools to stimulation the brain in specific ways to support the aging population in their daily activities in these spaces (in the field of attentional control during goal-directed behaviours).

Study of Iteration 1

Variation 1

Experience of Space

Cooking: As direct light enters in the space early in the day and leaves as the day goes on, the lighting of the space allows a person to understand the change of time and changes the feeling in the kitchen, its warmth. The curved walls give a sense of elegance and simplicity. The curve creates a natural path the user can follow. A direct exterior view brings the outside in, the open window brings in smells and sounds of natural and urban landscapes. The ceramics that make up the backsplash have a grounding effect, bringing the experiencer back to their roots. The theme of the attention is the backsplash and the curved counters. The rest fades slowly out of the field of attention, becoming margins.



Lighting Studies Experience Studies

Analyses Through Light and Experience Studies of Variation 1.
The views are taken at eye level, using a focal length of 22mm to simulate the human eye. The lighting studies were created using sunlight raytrace in the Rhino software. The sun parameters were chosen to create the most optimal conditions for lighting the space (September 21st 12pm, altitude of sun 45.7º. Location of space: Montreal Canada, lat 45.5º long -73.6º)

Serving: Wood and the ceiling from the dining area contrast with the kitchen's low ceiling, emphasizing the sense of awe; the wood structure reminds the user of a forest, and creates a sense of calm and serenity. The arched windows open the space up to the exterior spaces and connect the interior to the exteriors, the user feels part of the outside, reducing a sense of loneliness. The user can see the space they have left and the space they are going to (sense of understanding of space, and control over of the space). The theme of the attention is the table at the centre of the space.

The thematic context is the structure, and the margin is the ceiling and windows along the wall.

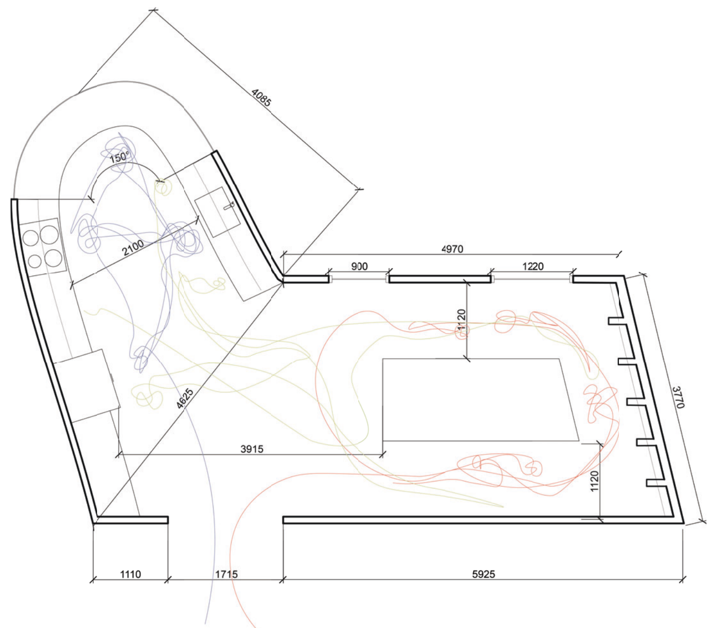
Eating: When sitting down, the feeling is overwhelming, because the ceiling is high. It could have the effect of awe or uneasiness. The view towards the kitchen provides a sense of understanding of the space and where the user is situated. The structure of the space also gives a feeling of being in a forest, a sense of contentment. The theme of attention is the windows. The thematic context is the table and the wooden structure, and the kitchen and ceiling become the margin of attention.

Movement and Embodiment

Cooking: Triangular composition allows for efficient movements within the kitchen area. The large prep space allows for better understanding of the task at hand; facing away from the dining area can reduce distractions from other parts of the space and, therefore, help situate the body in the space. There is neither a place for taking a break within the kitchen nor a specific area for storage. The space is too large, providing time to be distracted by the surrounding environment and what is occurring in it.

Serving: The kitchen-dining area is not separated by obstacles and provides for a good understanding of the space, allowing the user to get accustomed to it easily. Different finishings in both the kitchen and dining areas allow for the body to comprehend its surroundings. The movements are clear and easily manageable, but the distances are quite big, increasing the time it takes to get around and the opportunity for distraction. Because of this and the height of the ceiling, the user has a sense of being alone in a large space.

Eating: The dining area is large, and is a good space not only for eating but also for socializing. Without anyone there, it may feel too large, compared to one's body. This is emphasized by the height of the ceiling and the curves in the ceiling. The absence of fixed furniture provides opportunities for adaptations.

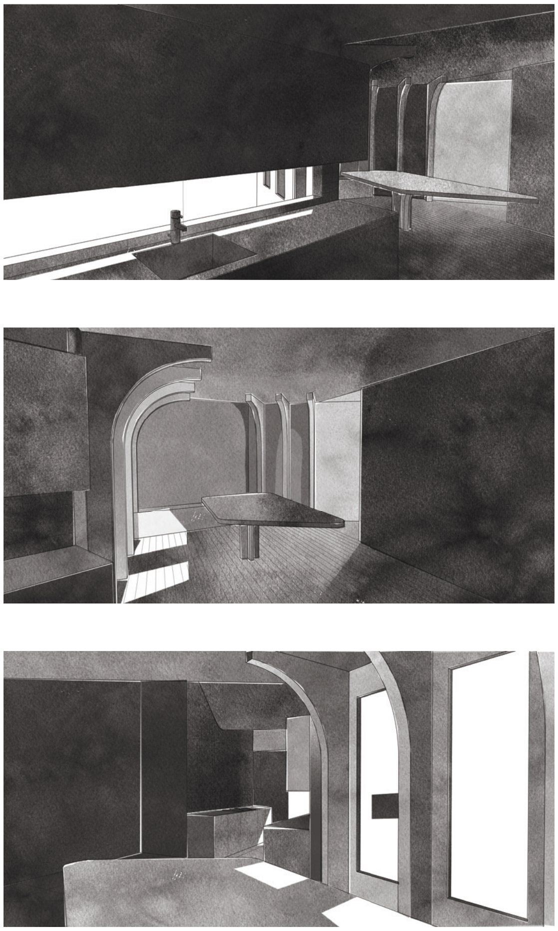


Movement and Body Studies

Variation 2

Experience of Space

Cooking: Morning light ensures the cooking area is well lit but, because of the height of the window, it does not interfere with the action, but instead promotes it. The curved ceiling is felt rather than seen and provides a sense of awe and immensity of space. The wood from the structure allows for closeness to natural materials. The user can understand the space visually, and this gives allows the person to feel safe. The large window is not facing the cooking or prepping surfaces but brings the exterior space into the kitchen in the thematic context of the field of attention. The theme is



Lighting Studies

Experience Studies

Analyses Through Light and Experience Studies of Variation 2.
The views are taken at eye level, using a focal length of 22mm to simulate the human eye. The lighting studies were created using sunlight raytrace in the Rhino software. The sun parameters were chosen to create the most optimal conditions for lighting the space (September 15th 10am, altitude of sun 41.8º. Location of space: Montreal, Canada, lat 45.5º long -73.58º)

the surfaces for work. The margin is the dining area and its structure.

Serving: As the user goes into the dining area, the entrance is visible to keep a good understanding of the space. The structure frames the dining area, and light enters from the southwest in the evening. The wood structure is the theme of the attention and highlights the fixed seating. The structure also brings order, orientation and direction to the space. In the margins of attention, the user sees the counter, the ceiling and the views through the windows.

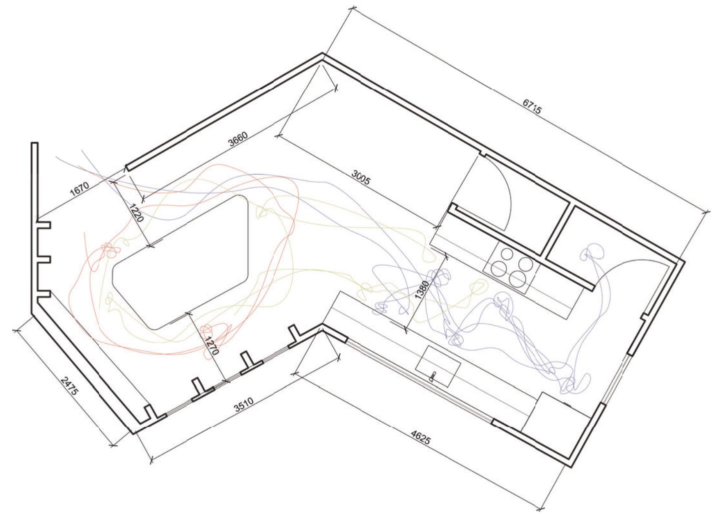
Eating: The large windows allow light throughout the afternoon and evening. The user feels in a different space than in the kitchen because of the differences in ceilings. The wooden structure is reminiscent of a forest. The framing of the light structures the space. The space can be understood while sitting on the bench. The table is the theme of the field of attention. The structure and exterior landscape through windows provide the thematic context and the kitchen is in the margin attention.

Movement and Embodiment

Cooking: The kitchen is a compact space, with two counters facing each other, which provides the most efficient movement around the kitchen (triangular composition). The counters are quite far from each other, reducing efficiency and increasing physical exertion. Storage space is just across from the cooking space, which also eliminates unnecessary movements. There is no area to sit, nor is there a good place for a person not cooking to interact with the cook. The body feels comfortable within the space and accessing elements, but it could be tightened up.

Serving: Access is easy and, due to the narrowness of the kitchen, movement needed between cooking and eating is clear. The person is repeating the same action and movements. There is no separation or obstacles. The openness contributes to an understanding of the space.

Eating: The low ceiling makes the space cozier, combined with the wood from the structure; you feel at ease in the space, with a good understanding of the surrounding spaces.



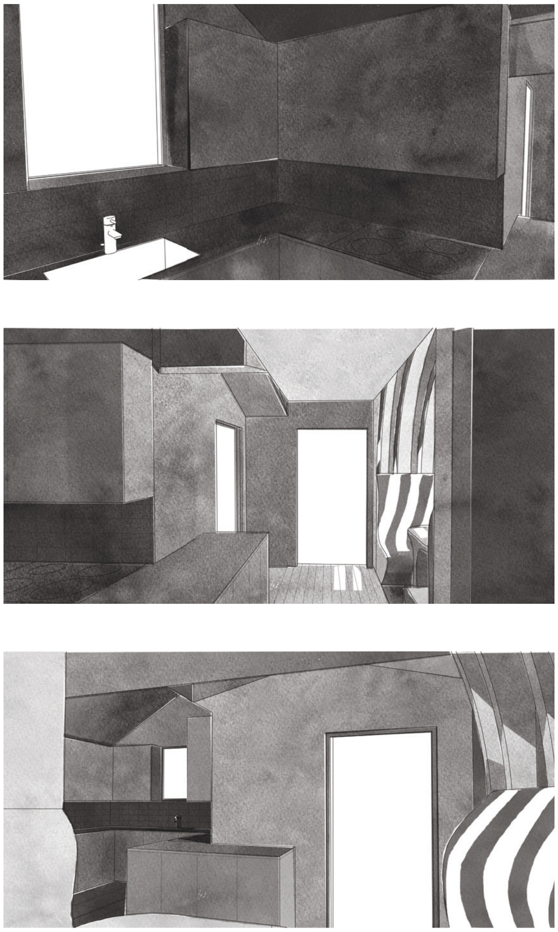
Movement and Body Studies

Variation 3

Experience of Space

Cooking: The U-shaped counters give the feeling of being in a nook, a small space. The angled roof makes the space feel larger and reduces the effect of confinement. The view to the outside while standing at the sink allows for a connection to the exterior and the window allows indirect light to enter the space. The theme of attention are the textures from the kitchen and the exterior view. The thematic context are the other elements of the kitchen and in the margin, the user sees the dining booth or the ceiling.

Serving: The experience is controlled and directed through the wood floorings that give a sense of warmth and coziness. The door on the side lets light in and provides a hint to exterior space. The bright dining area, almost like a greenhouse, is contrasted with the kitchen through the luminance. It feels like the user is in a narrow space and on both sides the space splits open. The theme of attention is the structure and light from the ceiling in dining area. The thematic context is the counter and the doors. The margin



Lighting Studies

Experience Studies

Analyses Through Light and Experience Studies of Variation 3.
The views are taken at eye level, using a focal length of 22mm to simulate the human eye. The lighting studies were created using sunlight raytrace in the Rhino software. The sun parameters were chosen to create the most optimal conditions for lighting the space (June 21st 2pm, altitude of sun 56.3º. Location of space: Montreal Canada, lat 45.5º long -73.58º)

is the ceilings in the other spaces, i.e., the circulation area and the kitchen.

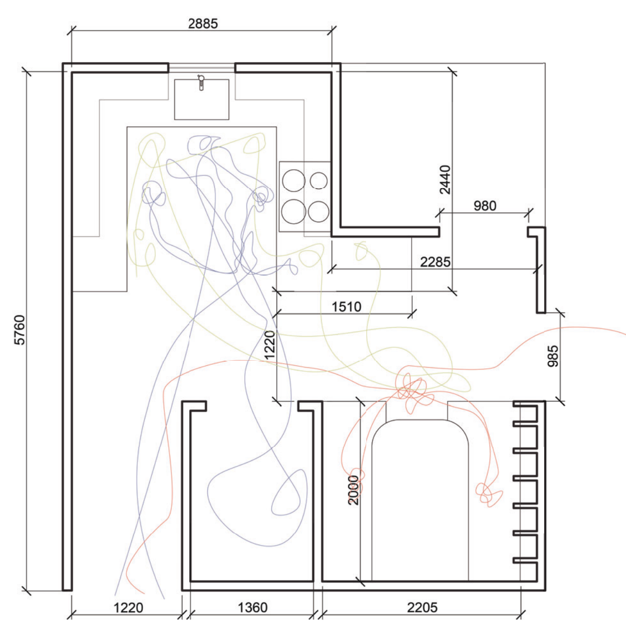
Eating: The space feels confined by its dimensions, but the light and structure brings a feeling of calm and there is a sense of not knowing where you are inside or out. As you eat, you can have a view to the kitchen, and ceilings allow you to delineate the spaces (circulation, kitchen, dining). The theme of attention is the ceiling and wood structure, the thematic context, the seating and table, and in the margins, you have the corridor and kitchen.

Movement and Embodiment

Cooking: The kitchen is compact, allowing the movements to be clear and easy to accomplish. The space is limited: because the whole space is small, it is easy to interact with people sitting in the dining area and this stimulation can provide the neural support for the action to be executed. The location of the pantry is optimal as it is nearby from the main cooking area.

Serving: The movements are defined since circulation between the areas is clear. Things are close to each other (reduced effort) The space is confined and could give a feeling of imprisonment and create physical obstacles to movements.

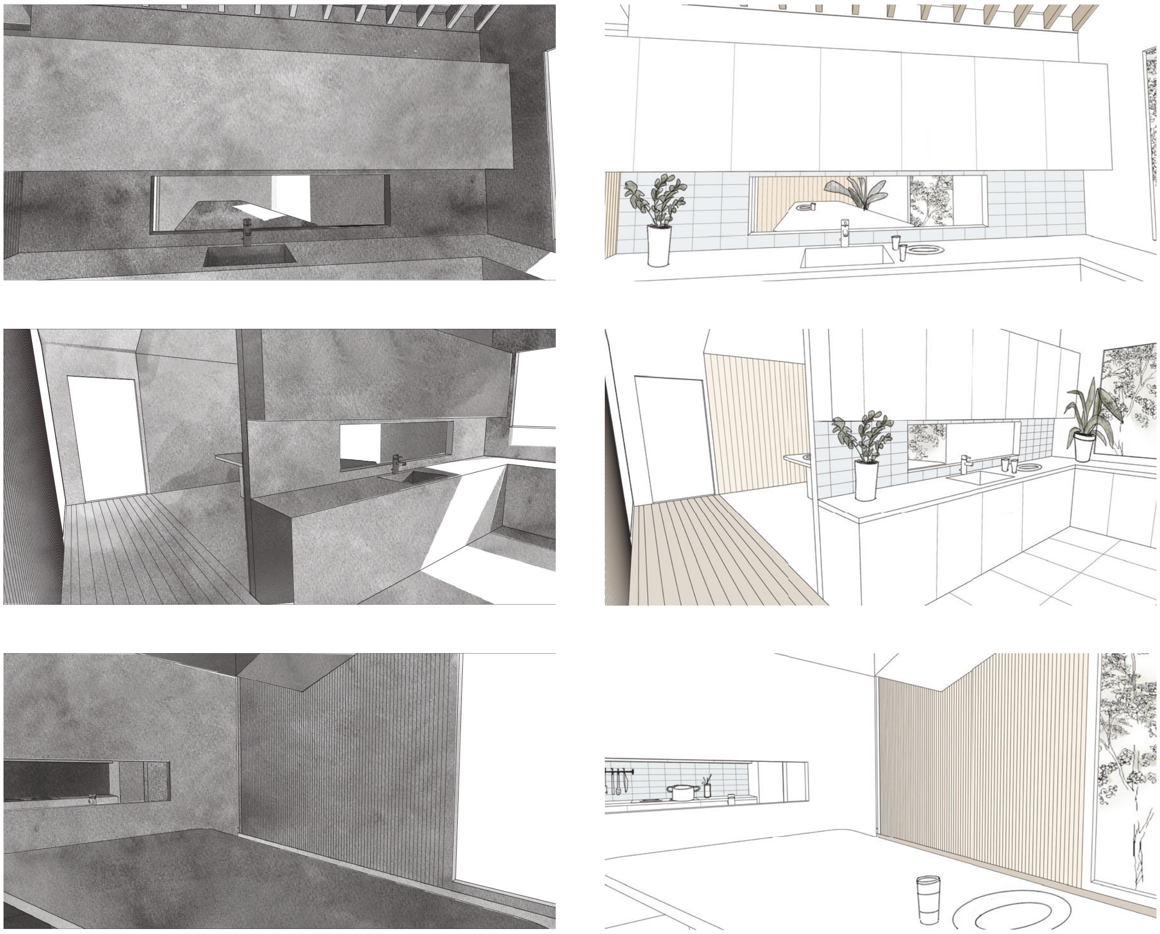
Eating: The space is tight, a confined space, reducing the distraction, optimizing the height and size of the dining area. It is not flexible (fixed seating) which can be problematic with aging populations. There is easy access to the outdoors, kitchen and storage areas.



Movement and Body Studies

Variation 4

Experience of Space



Lighting Studies Experience Studies

Analyses Through Light and Experience Studies of Variation 4.
The views are taken at eye level, using a focal length of 22mm to simulate the human eye. The lighting studies were created using sunlight raytrace in the Rhino software. The sun parameters were chosen to create the most optimal conditions for lighting the space (September 9th 1pm, altitude of sun 46.8º. Location of space: Montreal Canada, lat 45.5º long -73.58º)

Cooking: Lighting that enters through the large window illuminates all the cooking space and brings the exterior into the interior, providing a feeling of being within nature. The wood structure gives character to the space. A view to the dining area while cooking enables the user to understand their surroundings but also leaves more room for distractions.

There is a peak of wood texture on the wall of the circulation area, creating a sense of separation between it and the kitchen, and framing the spaces. The theme of attention is the window and the counter. The thematic context includes the kitchen ceiling and the wall in the circulation area and the margin is what is happening in the dining area.

Serving: The wood texture along the wall and the floors gives structure and direction to the action. It is easy to see both sides of the separation wall, but it does restrict movement and confines the person in the space. The light (direct and indirect) provides high luminance and gives a sense of safety and control. The different patterned ceilings differentiate the experiences in the circulation between the kitchen and dining area. The theme is flooring and wood walls. The thematic context is the table and the counter, and the margin is the ceilings.

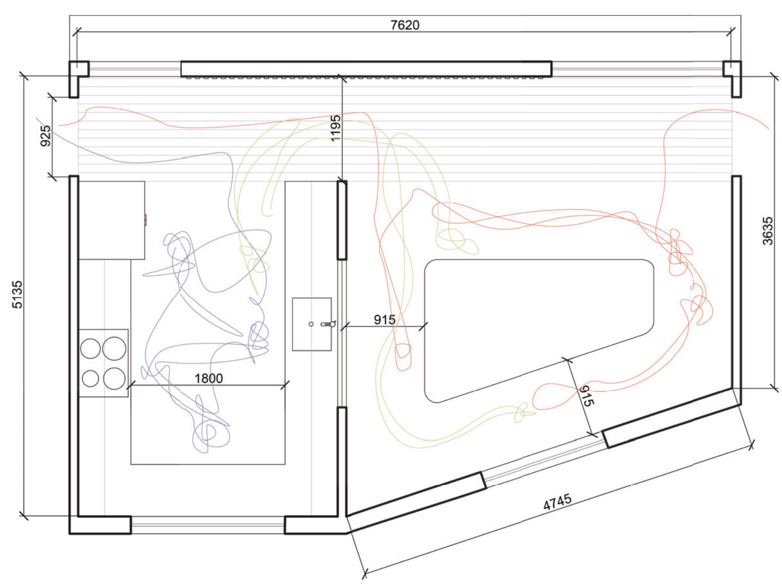
Eating: The ceilings are more evident when you are sitting at the table. This increases the feeling of openness because of the height of the ceilings. Light enters from both sides, illuminating the space, but also impacts the creation of atmosphere. The partial glimpse of the kitchen gives the user a sense of understanding of the space. The wood from the corridor brings coziness to the space. The theme of attention is the table and side window, whereas the textures of the corridor and the ceilings are more within the thematic context and margin of attention.

Movement and Embodiment

Cooking: Movement is efficient in the kitchen from the positions of the appliances (triangular composition), but the space between the two sides of the U-shaped kitchen is large, thereby increasing the distance and time needed to move around in the kitchen. The views to the dining area connect the user to the other spaces, giving a bodily understanding of the space. The U-shaped kitchen could give a sense of confinement, but the structure of the ceiling and the large window reduce that effect.

Serving: The action is always done in the same way because of the wall that limits movements. The wall provides structure to the movement. However, the view through the wall allows the user to perceive obstacles ahead of time. The spaces are close together, reducing the distances that one must travel to get to one from the other.

Eating: There is ample room to move around the table. It feels proportional to one's body and movements. The large windows could become distracting for the task at hand. There is a good view of the circulation area, hinting at the people around the corner.



Movement and Body Studies

Main Reflections

These variations are interesting examples of design solutions when the designer considers neuroscience alone in the design and does not integrate other architectural strategies into design of these spaces. The solutions that arise may not “work” as final design solutions because they overlook some key components that architects focus on through their design iterations. Looking through this architectural lens, and considering the observations and analyses made about the experiences of the user (both bodily and mentally) as they move through space, there are three elements that emerge that could propel the design into the realm of “good design”:

1_Points of Entry and Circulation: The designer must consider the way people will be entering the space, whether it has multiple entries or not. The views and experiences as the user enters the space, whether it is directly into one of the main action areas or into a circulation area, will affect the rest of the experience of the space. The means of entry creates a foundation for the understanding that the user will have of the space. It can also impact the sense of security that one can have, allowing the feeling of autonomy to become stronger within this space. The views that the user would face upon entering the space can be nil, thereby eliminating all sense of mystery or, on the contrary, can give a hint as to what is happening in the space and provide the necessary tools to understand it. This could make the discovery of the space interesting for the user, a sense of newness with potential for new neural learning. Points of entry and circulation also include the relationship between the kitchen-dining space and the exterior space. This exterior space can be viewed as an extension of the kitchen-dining space, providing additional areas of action and allowing for new possibilities for stimulation of brain areas and pathways.

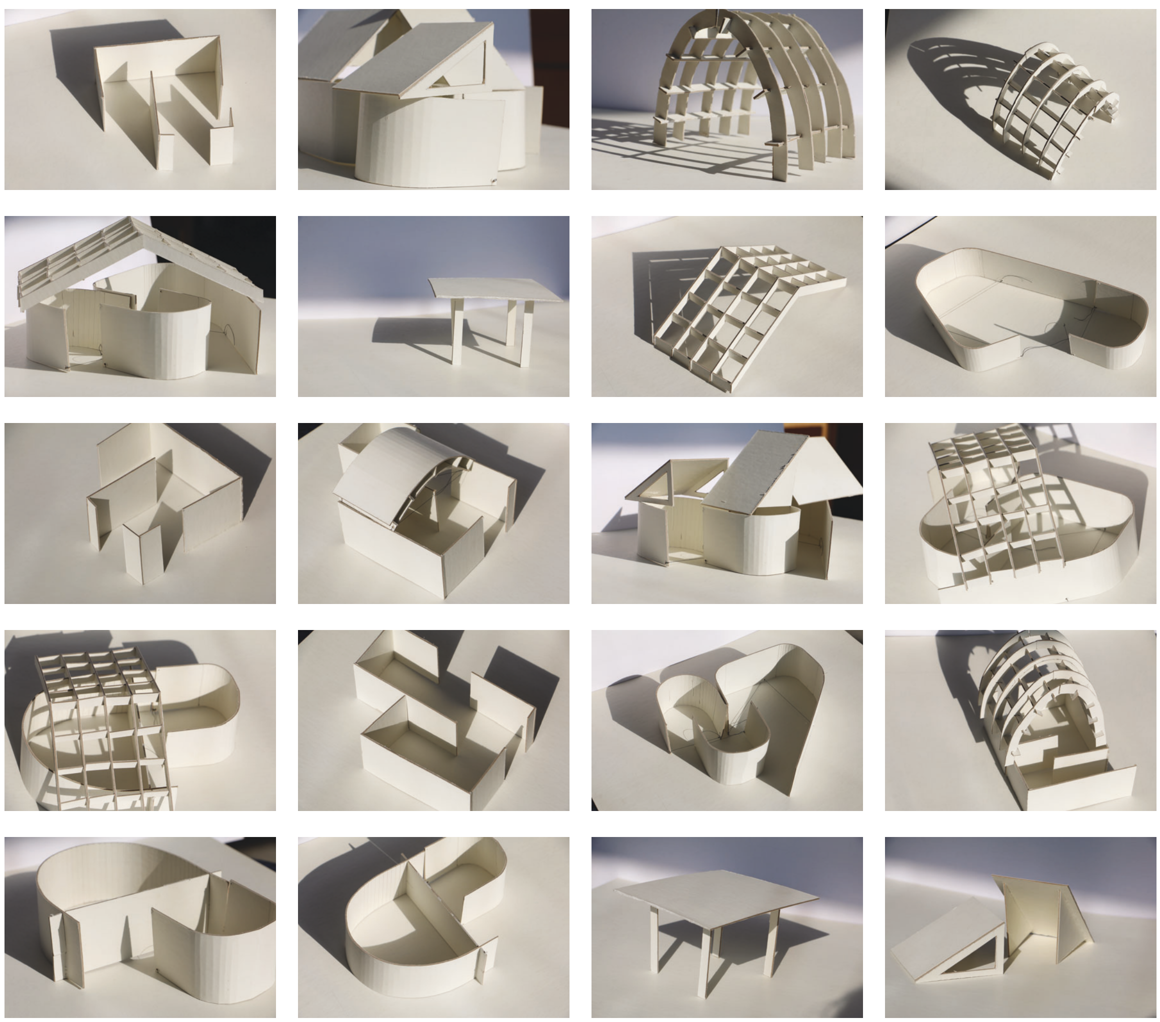
2_Orientation and Direction: The designer can consider the means of orienting the user in the space. There are various tools that architects use to give the support needed so that the user can situate themselves in the space quickly. In the following iteration, considerations of structure, materiality, lighting and dimensions of the space are essential to stimulate wayfinding structures in the brain and reduce the cognitive load by giving cues in space for the user to find their way around. The kitchen and dining areas should be separated from each other, to avoid overstimulation during the performance of a specific action, and the separation can be also a means to orient movement in space for the serving action. Ceiling heights, wall configuration can play with orientation of the space and the light that enters the space, hinting again at directionality of the space and where your body is situated with respect to the exterior and the rest of the unit (or the other action areas of cooking, serving and eating). Finally, materials for flooring, walls, backsplashes as well as the colours for these elements should be considered as they could distinguish spaces for action and movement through the space.

3_Cohesive Architecture: The first iteration demonstrated a lack of overall cohesive expression of design. As mentioned by Sussman in her principles, architecture takes on all its impact and importance when it tells a story through the design and at every scale of design (from details to structure and shapes of the spaces) (Sussman and Hollander 2021). To do so, the second iteration must look at the different scales of the architectural design and determine how the different elements of design can give the atmosphere and experience of the space and provide the neural support necessary to perform the actions of cooking, serving and eating. The designer seeks to create spaces that are molded to form optimal experiences and these experiences together highlight the story that the design is creating. The cohesive nature of the design can be achieved by using the neuroarchitectural features in thoughtful ways, thinking, for example, of how curvilinear features can work with rectilinear features to balance stimulation in the space. The walls, roof structure, openings in the walls and ceilings serve a purpose for embodied experience and orientation. The contact between the user and the architecture becomes the means for the experience of the space. The narrative of the space provides the user with a unique experience, that in turn supports physiological and physical functions for the actions. It is the architect's task to balance architectural features for stimulation and storytelling.

Iteration 2 - Architecture in Support of Neuroscience

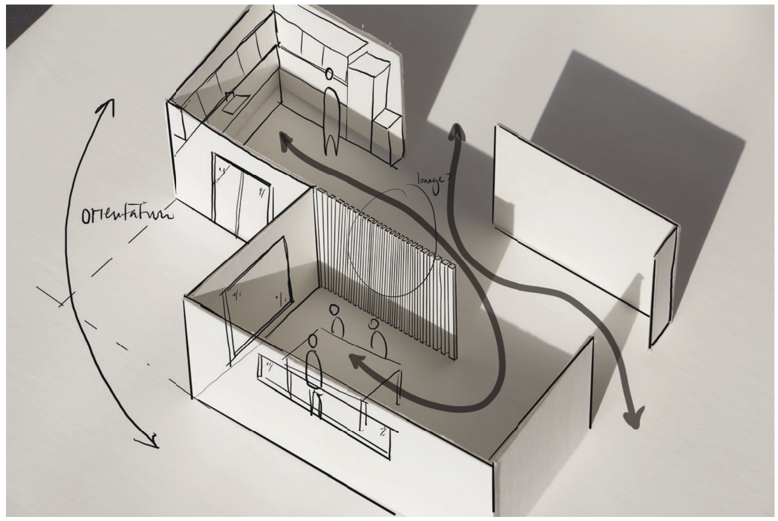
Iteration 2 stems from these observations and looks at adding to the first iteration by seeking to understand the role that architecture can have in expressing the NAF and supporting the neuroscience research in how we perceive space and how it affects us. This iteration looks at providing the previously mentioned cues necessary to reduce the user's cognitive load through architectural strategies while also offering an enriching experience for all aspects of human action in the kitchen-dining space.

The three main observations raised in the previous section become the starting point for this second iteration. The objective is to benefit from architectural knowledge and strategies to provide increasingly thoughtful design solutions. Even though architecture (and the analyses through phenomenology and embodiment) become the tools that drive the design of the kitchen-dining spaces, the characteristics provided by the NAF are essential in the discourse. The two variations developed stimulate the brain areas, pathways and mechanisms discussed previously using different architectural tools. As for the first iteration, physical models were the means of exploration of the observations. This series of models explored different shapes and dimensions for enclosing space as well as



These photographs of physical models are the exploration of points of entry and circulation, architecture that “works” and orientation through light and structure roof structure and shape. Using sunlight, the models were photographed, combining different models to create different studies of the spaces to be created.

Variation 1

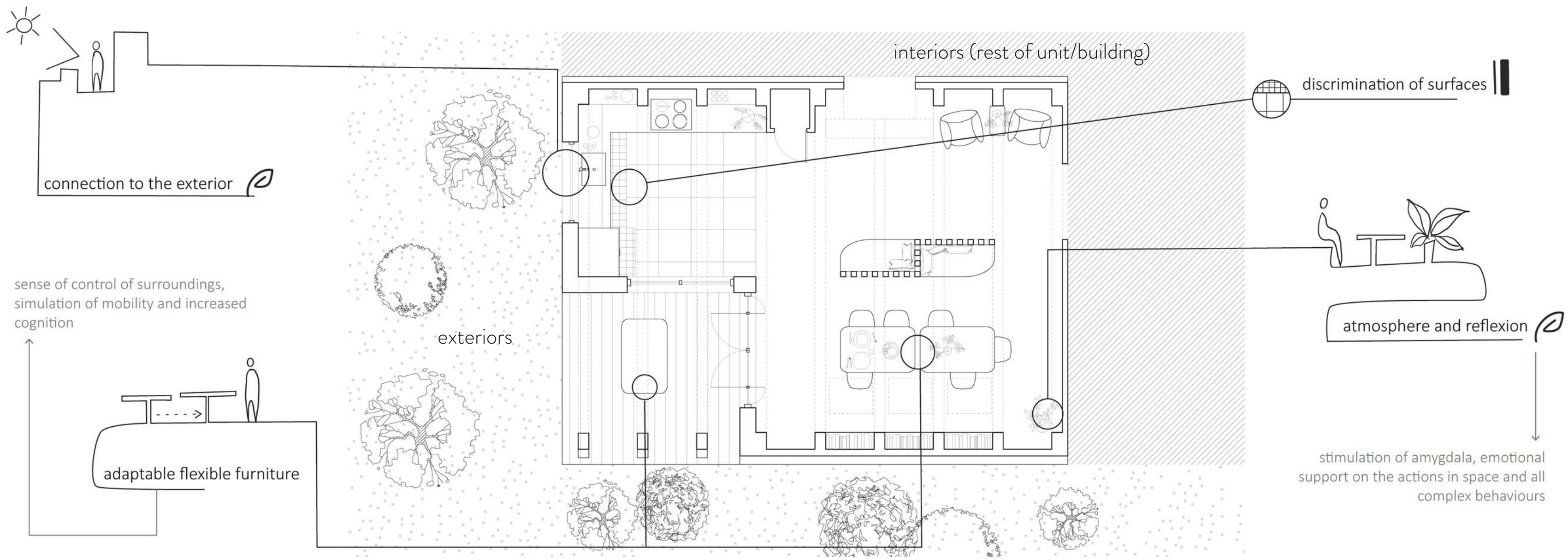


This image studies the circulation, movement and points of entry of the variation 1. The photograph and sketches give the scale to the physical model. The natural lighting used to analyze the optimal angle for this variation.

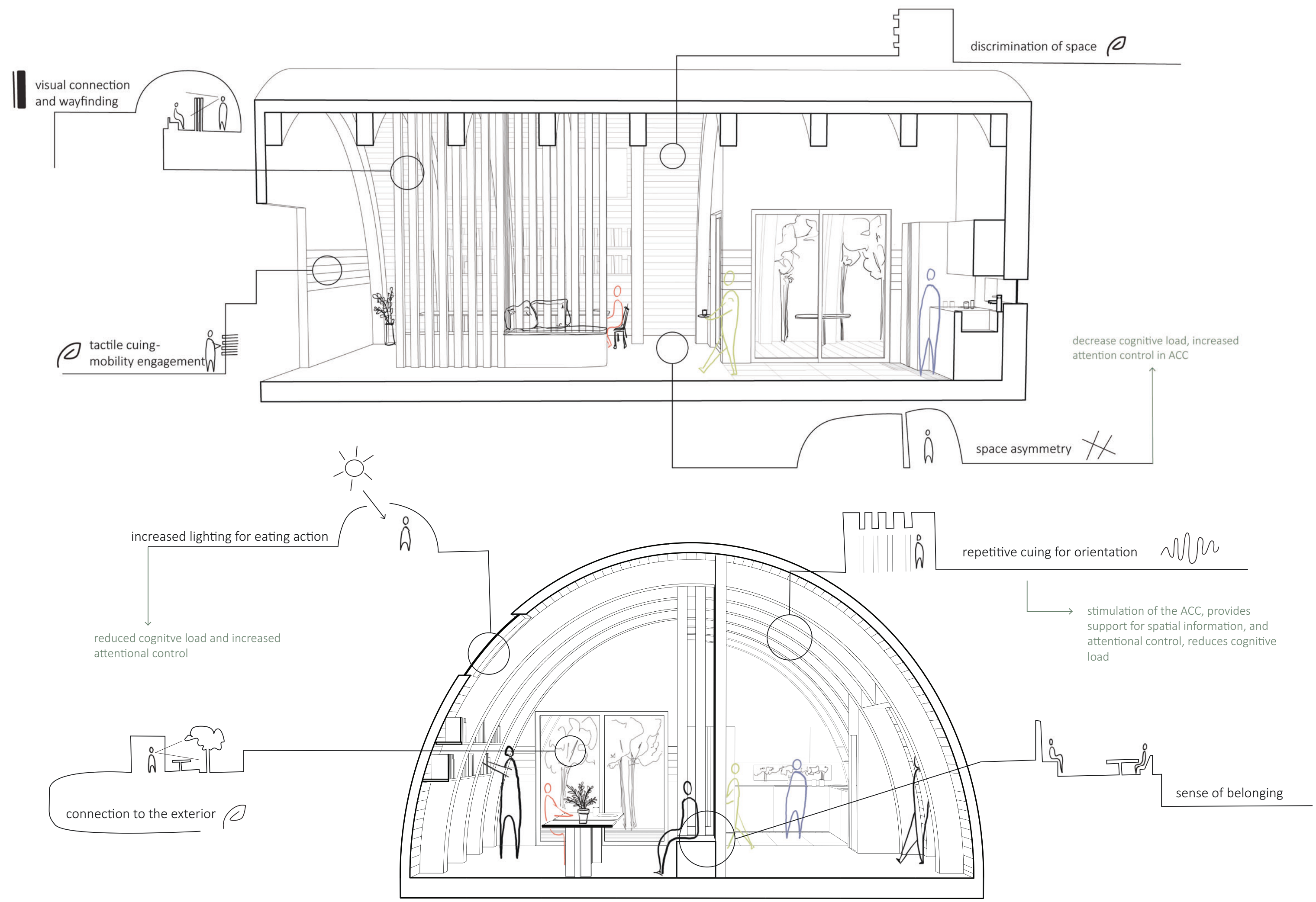
This variation explores the roof as the main enclosure of the space. The roof creates both roof and walls in this variation. Its structure and the wood panelling on the inside walls orient the user within the space. It provides repetitive cuing to the user across the space with the rhythm of the materials. The arched structure is visible for all three actions and stimulates the brain through a curvilinear feature (providing neural support).

The plan is simple. The walls not created by the roof are rectilinear, and do not need more complexity to them, the movement and circulation of space being shaped by the roof and its structure. Along those walls, the same wood panelling from the other walls extends for a 60 cm high area (between 120 and 180 cm) providing a tactile cue for moving through the space for users with minor visual impairments. As users enter the space, the open nature of the layout gives them a sense of security and offers support to their wayfinding strategies in the space. The wood slate wall between the kitchen and dining space provides some mystery or discovery of space, stimulating areas of learning and encoding as well as emotional connection areas (amygdala and anterior cingulate cortex). The windows are strategically placed to connect the user to their surroundings, both the exterior spaces and natural landscapes, and provide high luminance in the action areas of cooking, serving and eating.

The furniture designed for the space allows for various configurations, making it adaptable to different group sizes. The two tables can be separated and positioned in between the structure or brought outside on the terrasse through the rotating doors. Their dimensions provide more opportunities for unique configurations, and the users become masters of the space. Seating is available at the centre of the space, for a brief pause during movements from one space to the other, and for possibilities for social encounters during the execution of the actions. Both the flexibility of space as well as social interaction possibilities gives a sense of belonging to the user, promoting areas in the amygdala and the insula related to emotional cuing.

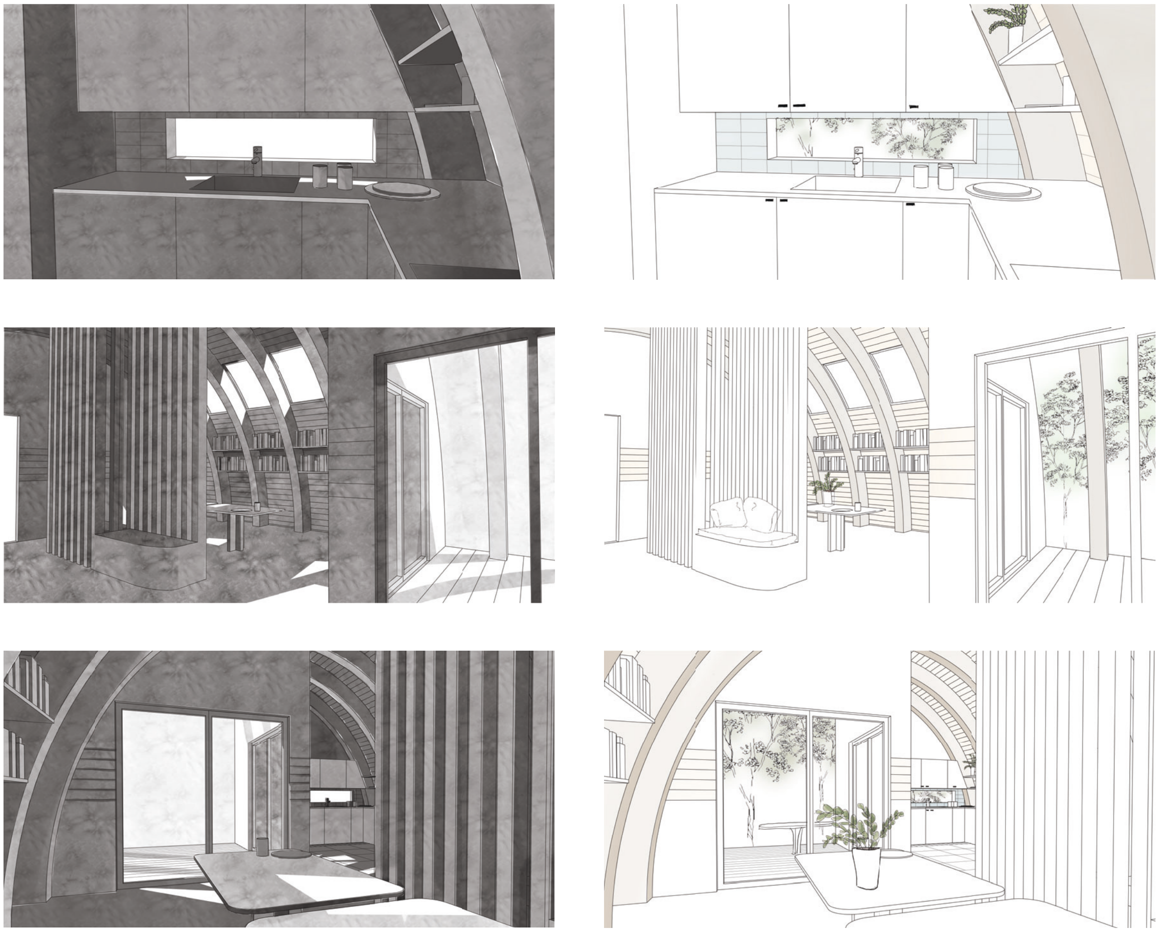


Floor plan of Variation 1. In the floor plan, architectural elements are highlighted for their impact on the experience of space, the way the body responds to the environment and the neural stimulation that are targeted. The two different hatches suppose the possible connections that the kitchen-dining space would have with the rest of the unit/building.



Horizontal and Vertical Sectional Perspectives of Variation 1. In the sections, architectural elements are highlighted for their impact on the experience of space, the way the body responds to the environment and the neural stimulation that is targeted.

Experience of Space



Lighting Studies Experience Studies

Analyses Through Light and Experience Studies of Variation 1.
The views are taken at eye level, using a focal length of 22mm to simulate the human eye. The lighting studies were created using sunlight raytrace in the Rhino software. The sun parameters were chosen to create the most optimal conditions for lighting the space (August 21st 2pm, altitude of sun 48.7º. Location of space: Montreal Canada, lat 45.5º long -73.58º)

Cooking: The main lighting enters through the side door onto the cooking area. The window in front of the sink provides direct views towards the exterior, giving a sense of peacefulness as the user cooks. The curved structure from the roof shapes the space of the action and the wood from the panelling and the structure provides a sense of comfort and softness to the space. The shape of the cabinets and the open shelving feel intentional, offering different opportunities for storage. The counter and the window are the theme of attention. The structure and panelling are the thematic context and the light from the door is the margin.

Serving: The open nature of the space allows the serving action to be fluid from the kitchen to the dining space. The light from the doors towards the exterior terrasse naturally creates a path to the dining room. The wood along the wall gives visual and tactile cues to the user. Again, the presence of wood along the full movement of the action softens the space and the flooring in the kitchen contrasts with the flooring in the dining and circulation areas. Light from the high curved windows highlights the tables in the dining space, making this the theme of attention. The thematic context is the structure and the wood partition. The margin is the light and views coming from the doors towards the exterior.

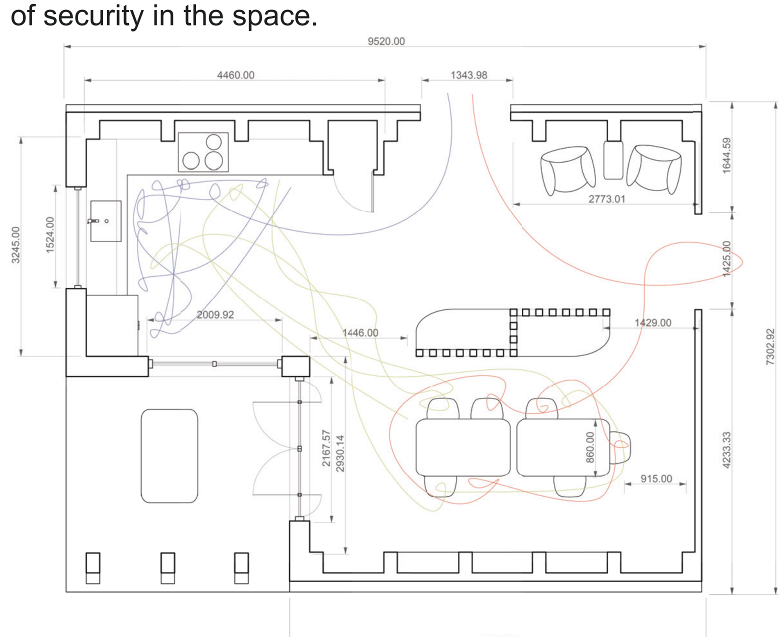
Eating: As the user executes the action of eating, the wood slates from the partial separator of space and the structure of the roof frame the experience. The light entering from the top windows provides a luminance directly onto the action area and floods the user as well. The views towards the exterior connect the user to the natural landscape. The theme of attention is the table, the thematic context, the bookshelves and the wood structures. In the margin of attention, are the natural views and the kitchen.

Movement and Embodiment

Cooking: The kitchen's layout is a great example of triangular composition, the most efficient kitchen layout for movement. Though the kitchen is in an L-shape, the user's body does not feel restricted because the ceiling increases in height in the space, and there are sufficient surfaces to work on. The pantry is within the space, reducing unnecessary movements to acquire ingredients during the cooking action. .

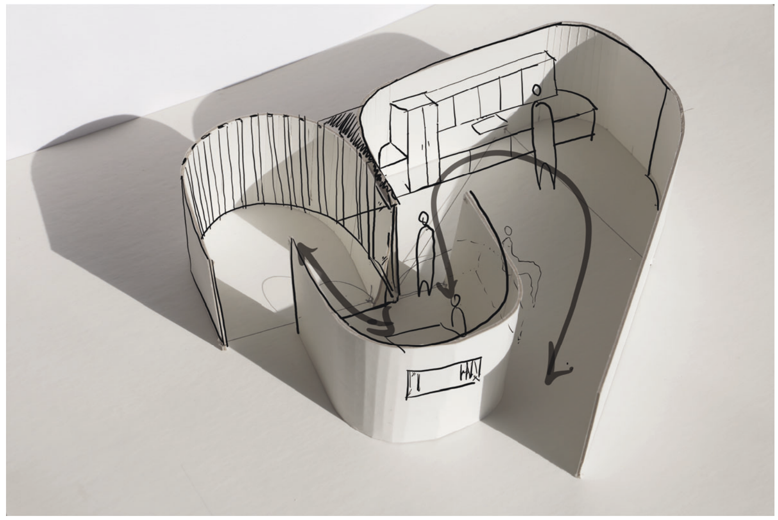
Serving: The action of serving is easy framed by the central seating space. The seating creates a narrower circulation space that concentrates the attention of the user as they execute the action of serving. The distances between the kitchen and the dining area are not too great as to distract from the action. The constant visual cuing through the wall panelling and flooring connects the action in the space.

Eating: The flexibility of the furniture provides the opportunity to make the space the most comfortable for the user's body, depending on the circumstance. This means that the user can reduce the size of the table if they are alone, reducing the emotional impact that a large table may have on comfort, sense of belonging and loneliness. Though the ceiling is high, the structure confines the space and creates a sense of security in the space.



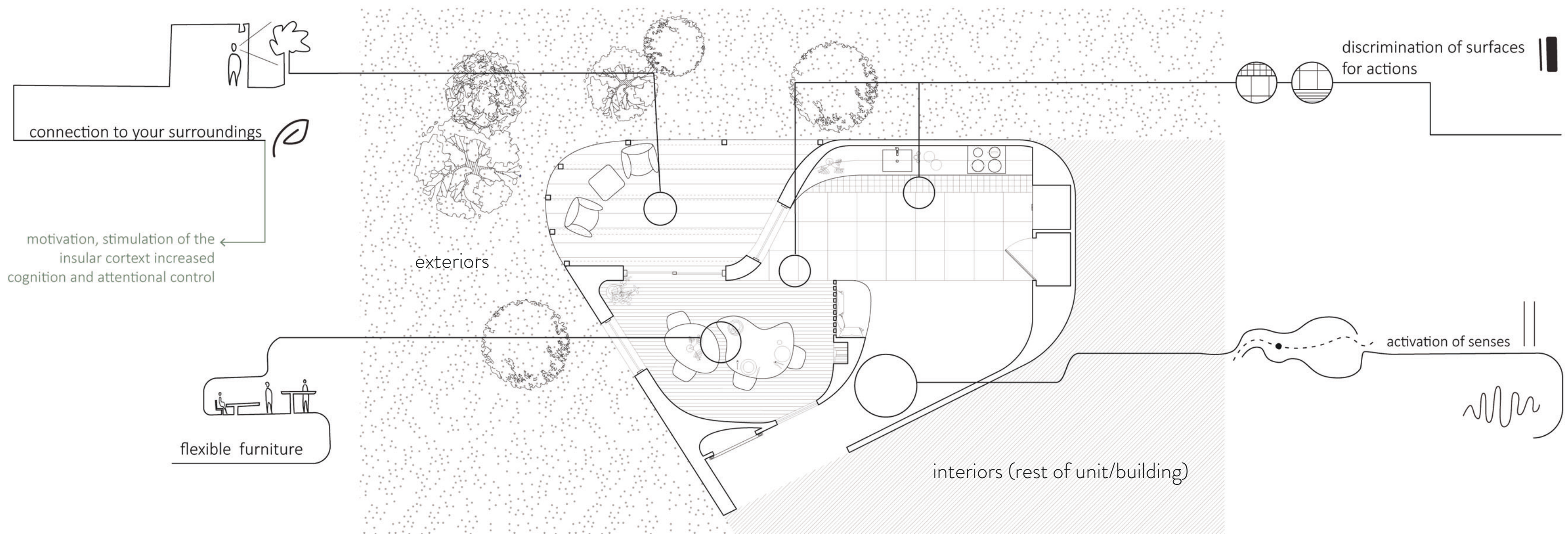
Movement and Body Studies

Variation 2

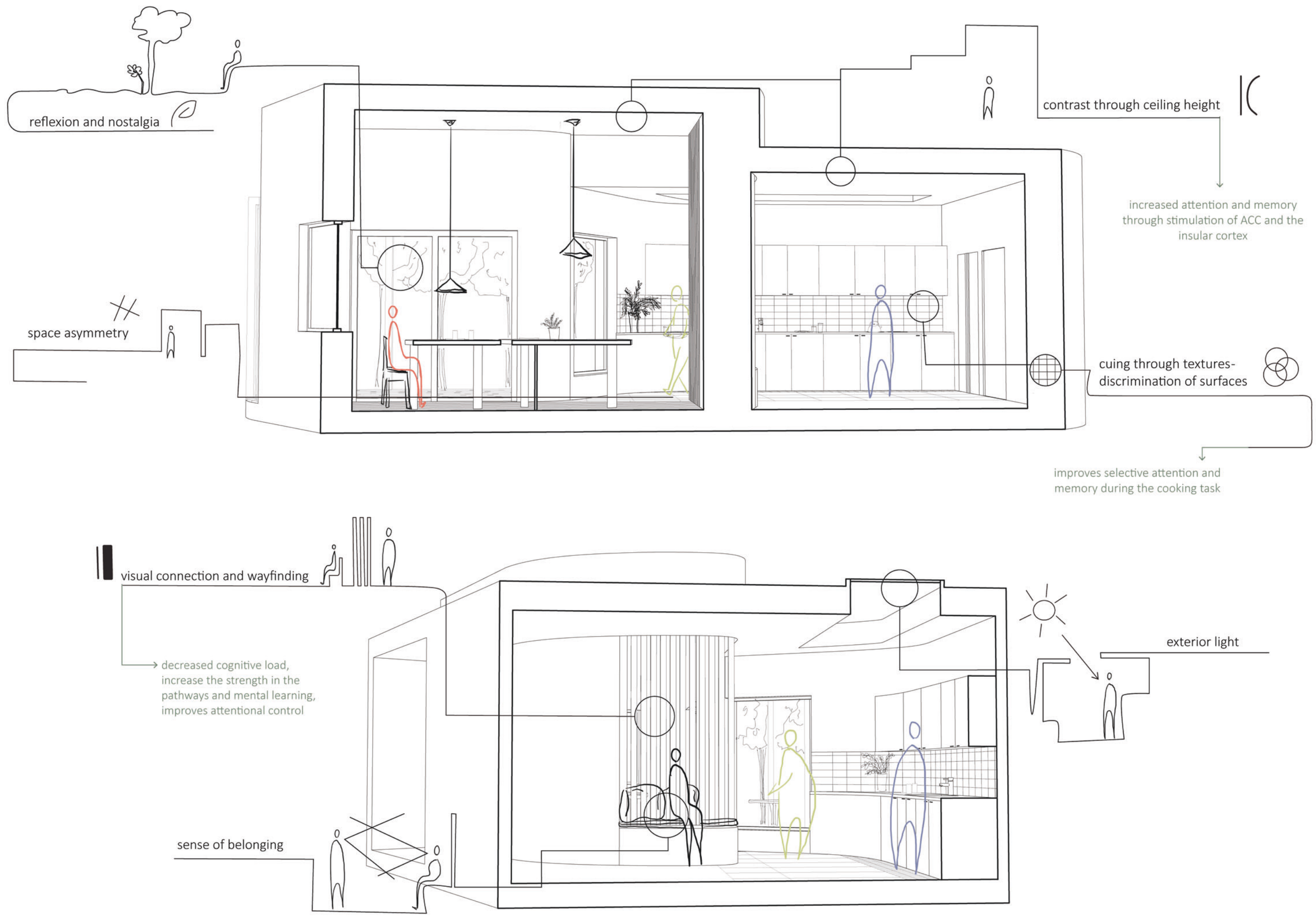


This image studies the circulation, movement and points of entry of the variation 2. The photograph and sketches give the scale to the physical model. The natural lighting used to analyze the optimal angle for this variation.

In this second variation, rather than using the roof as the driving force to orient movements and circulation through the space, the walls are the architectural elements that do this. The walls are curved in such a way as to invite the user into the space and propel them to each of the action areas. The entrance to the space is along a corridor, the curved walls directing the movement. As the user walks, they get a first glance of the dining space through an interior viewing window. A contrast is created between the narrowness of the corridor and the larger space of the kitchen. Different flooring materials delineate the space as do the different ceiling heights. The user may not, at first glance, notice these details, but they provide the cues necessary to separate spaces for the different actions. The tiling of the kitchen becomes smaller as you get within 30 cm of the counter, giving tactile cues for wayfinding, and grounding the user in the space. Distractions are reduced by using the texture of the floor as a focus point. The strategically placed windows, door and skylight increase natural lighting for eating and cooking, which reduces the cognitive load required in lower lit spaces, and increases the attentional control required for the execution of these actions. The made-to-measure furniture is created to be moved around to accommodate various group sizes. The curves of the furniture follow the curves of the dining space, fitting along those walls when moved around. The exterior is directly connected to the dining space, and the views of this space are visible from both the kitchen and the dining space. This provides further support for the user to orient themselves in the space and awakens emotions such as reflecting on oneself and nostalgia. The change in dimensions and proportions between the kitchen and dining area creates an asymmetry, stimulating the overall cognition, learning and encoding.

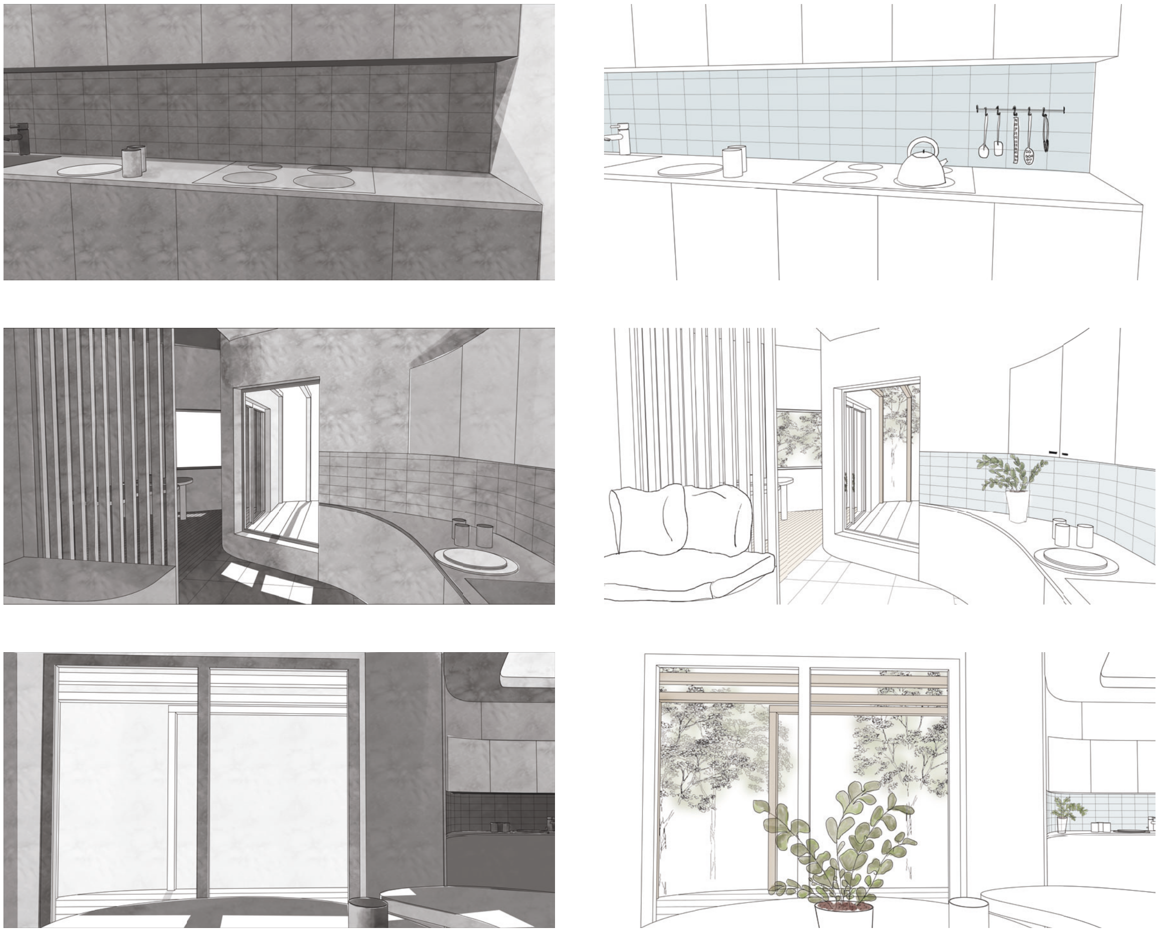


Floor plan of Variation 2. In the floor plan, architectural elements are highlighted for their impact on the experience of space, the way the body responds to the environment and the neural stimulation that are targeted. The two different hatches suppose the possible connections that the kitchen-dining space would have with the rest of the unit/building.



Horizontal and Vertical Sectional Perspectives of Variation 2. In the sections, architectural elements are highlighted for their impact on the experience of space, the way the body responds to the environment and the neural stimulation that is targeted.

Experience of Space



Lighting Studies Experience Studies

Analyses Through Light and Experience Studies of Variation 2.
The views are taken at eye level, using a focal length of 22mm to simulate the human eye. The lighting studies were created using sunlight raytrace in the Rhino software. The sun parameters were chosen to create the most optimal conditions for lighting the space (July 25th 12:30, altitude of sun 63.2º. Location of space: Montreal Canada, lat 45.5º long -73.58º)

Cooking: The simplicity of the cooking area gives a sense of control over the space. Lighting flows onto the cooking area from the skylight, reducing direct sunlight and providing overall light (reduced contrast between dark and light spots). The coloured backsplash livens the space. The textures on the floor provide tactile cues to direct attention towards the counter and cooking space. The lower ceiling in the cooking area gives a feeling of security to the user. The theme of attention is on the counter. The thematic context is the backsplash and light across the cooking area, and the margin is the window towards the exterior.

Serving: The curved walls direct movement towards the dining area. The wood partition allows the user to see their destination, but doesn't create obstacles. The large window along the path brings lots of light and natural views during the serving action. The possibility for rest in the informal seating integrated in the separating wall provides opportunities for social interactions. The wood from the structure brings in a sense of warmth. The textures on the floor cues the user through touch during the action of serving. The theme of attention is the wood wall partition and the dining table. The thematic context is the views through the kitchen window and door and the margin is the dining room window.

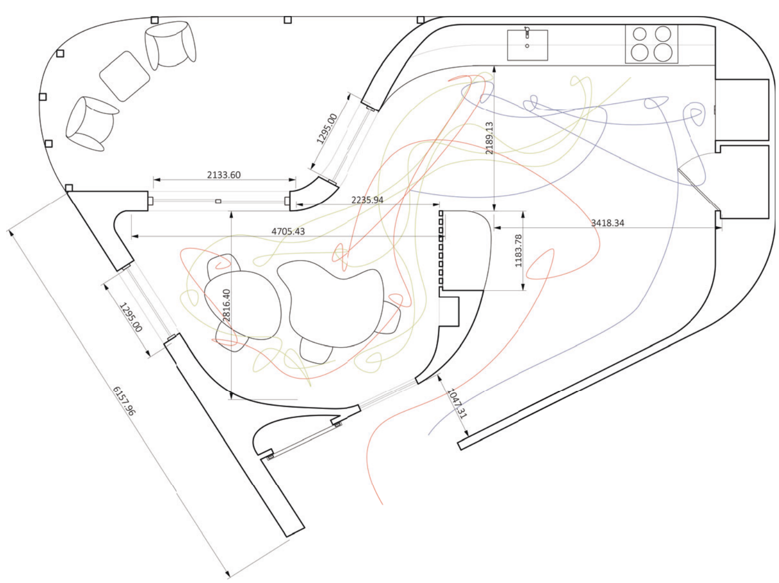
Eating: The ceiling in the eating area is higher and this creates the impression that the space is larger than it is, giving a feeling of liberty to the user. The views to the exterior space are prominent during the action. Depending on the time of day, light can enter from the side window or the large patio doors. Combined with the natural landscapes, this light gives the experience a calming atmosphere. The theme of attention is the table and the view. The thematic context is the wood separation, and the margin is the kitchen view.

Movement and Embodiment

Cooking: The textures in the kitchen are used to provide support to the movements required for the cooking action. The pantry is right next to the fridge to be as easy to access as possible. Both are integrated in the wall, reducing obstacles for movement in the kitchen area. The ceiling's lower height reduces the scale of the space to an intimate level, making the body feel at home and this creates a strong emotional link between the cooking action and the kitchen space.

Serving: The curvature in the walls and the wood separation provide the wayfinding support for the serving action. Narrowing the space and creating an entrance to the dining space also encourage mobility and wayfinding. This entrance is proportioned not to make the user feel constrained, rather pushed through to the other space.

Eating: The furniture molded along the curves of the walls create distinct paths to get to the eating action areas, and also provides the opportunity for different body positions during the action of eating. The tables can be moved and enable the user to adapt their own space according to the number of people with them. The user can also have various points of view and be more or less stimulated by the space, depending on the place they decide to use for the action of eating.



Movement and Body Studies

Chapter 6: Conclusion

In this thesis, I set out to test the idea that neuroscience can and should be actively used in the process of designing spaces, and that it is particularly beneficial in the case of more vulnerable populations such as the senior population. The iterative process used allowed me to explore the role that neuroscience can take in the design process as well as the role that architecture could have to drive research in neuroscience. By using phenomenology and embodiment as tools for the analysis of architectural design and experience, the study of these roles is deepened and can lead to more significant results and future research propositions.

Neuroscience in the Service of Architecture

Neuroscience can provide architects and designers with an understanding of the human brain and body that has potential for new innovations in design strategies. The knowledge about how our brains and bodies are affected by spaces, and how in turn spaces affect our physiology and psychology are essential tools for designers of spaces made for humans. To this day, this knowledge is not taught nor is it used in the design of spaces.

The first iteration is the demonstration of a methodology to transfer the neuroscience data into terms and elements that architects understand and can use to drive their designs. The methodology proposed in this thesis is a prototype that undoubtedly needs to be refined and revised to become an efficient tool for designers.

Architecture in the Service of Neuroscience

Using neuroscience as the starting point, designers can learn from the way we act and react to space, and introduce architectural tools, what I have termed neuroarchitectural features, such as structural elements, including textures, materials, shapes and light, as tools to stimulate the brain in specific ways. These design strategies can provide new hypotheses that could be studied in the context of neuroscience research to determine exactly how the brain is being stimulated by these elements. By creating cohesive architectural design strategies, which could simply be considered “good design”, I believe we are creating better spaces overall. If we can then integrate this knowledge into neuroscience, we can provide better support for the brain, particularly in seniors who are starting to experience different sorts of declines. Architecture can offer new avenues for neuroscience studies on how we are affected by spaces.

The second iteration explores how architects can draw on their architectural knowledge to provide support for the neural networks for the user group, in this case, autonomous and semi-autonomous seniors. It also has the potential to hypothesize on the effect of the design on the brain and body. This could be tested through neuroscience research to uncover new means of stimulating the brain in designed spaces.

This thesis proposes an innovative methodology to integrate neuroscience knowledge and data into architectural design, not merely in a theoretical context but in practice. Because this is such a new and largely uncharted field, this thesis needs to be considered as a jumping off point. Next steps would certainly include testing the stated hypotheses about the effect of space on the brain using a real built environment, and recording brain waves and interviews with the people that would be living in these spaces. My hope is that this methodology can be further enhanced to provide new tools for better adapted spaces for many different populations of users.

Appendix: Brain Areas and Functions

This is an excerpt from Chapter 3 of London, 2020. Refer to this work for all sources used in the appendix.

Prefrontal Cortex

The prefrontal cortex (PFC), as its name suggests, is located at the front of the frontal lobe of the brain (Figure 1). It is adjacent to the premotor area (right behind the PFC) and runs above the central sulcus. Being part of the association cortices of the brain, the PFC covers a multitude of different functions. One of its major functions is in the planning of complex cognitive behaviours, goal-oriented tasks. These are also called executive functions. The dorsal lateral PFC (DLPFC) is a particularly important area in terms of this paper as it is directly involved in working memory. Working memory is described as temporary storage of information specifically created for motor planning and subsequent actions. Studies on monkeys have shown that neurons in this area have what is called a memory field and store

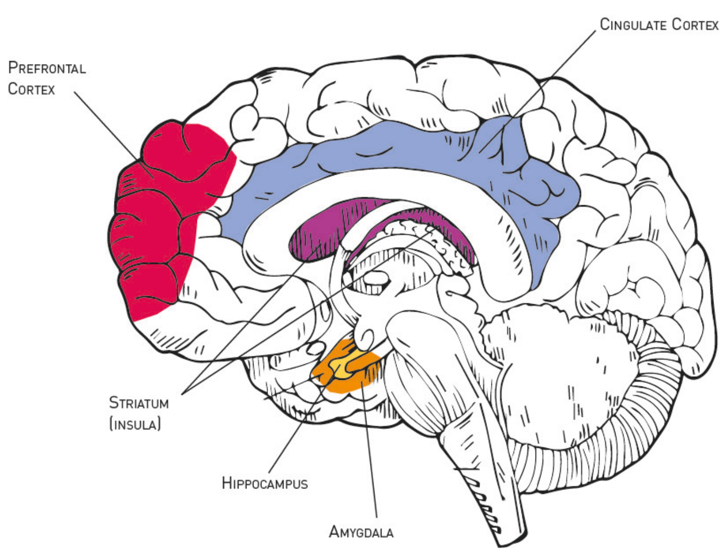


Figure 1

information as a guide to response in the near future, to ensure “behavioural continuity”. Studies in the visual field with respect to memory have also shown that the PFC encodes a map of the contralateral visual field in order to drive the working memory responses. The discussion of memory and working memory is particularly relevant in our case as there are declines in memory in the older adult brain (episodic memory, which I will not cover, is related to hippocampal deficits. See Figure 1 to visualize the position of the hippocampus). The working memory component that is mostly encoded in the DLPFC is the attentional control of visual and other perceptual information for subsequent action. The DLPFC is also one of the most interconnected areas of the brain. It has strong neural connections with limbic structures such as the amygdala and the cingulate cortex, two regions discussed below. This leads to conjecture that the DLPFC has an evaluative component of emotional reactions. Though there are distinctive differences in the functions of the left and right hemispheres, I will not delve into these, but will instead focus on key information relevant to the subsequent discussion on design. In short, the PFC, more specifically the DLPFC, is involved in regulating behaviours, by focusing attention needed for working memory and targeting specific areas such as the limbic system for the accurate response to a stimulus. Many different studies have shown that there are major deficits in behavioural responses in the elderly, and that these deficits have been correlated with changes in the PFC. The executive functions of the PFC are affected as the brain ages. One of the hypotheses is that many of the dopaminergic connections in the PFC are lost or weakened when the brain ages. These dopaminergic receptors are involved in the regulation of attention and the modulation of response regarding context-related information. This leads to problems in attentional control and short-term (working) memory for appropriate behaviour responses. These behavioural results are key to understanding the coping mechanisms that may occur as the brain ages, which will be discussed below.

Amygdala

The amygdala is part of the limbic system. The limbic system has mainly been associated with functions in emotional responses and processing of reward information related to actions and stimuli. The amygdala is surrounded by the cortices, in such a way that it is not possible to see it from the outside (Figure 1). It is a subcortical structure. The functions of the amygdala are to this date still being explored. However, a large body of research has associated the amygdala with emotional experience. More specifically, the amygdala has been an association area between information coming from the visual cues and the interpretation of the stimulus into emotional reactions to it, particularly fear. The amygdala mediates learned emotional responses to stimuli. The amygdala is involved in both autonomic (involuntary) emotional responses as well as the cognitive expression of emotion. Therefore, the amygdala is intimately connected to the PFC (and the DLPFC). From lesion studies, we have learned that the amygdala seems to be a connecting centre, where the information of a stimulus is associated with an emotional response (often aversion or fear) rather than being the expression of that emotion. It is then encoded into the hippocampal formation. The interconnectedness between the amygdala and the hippocampus allows us to better understand the strength of the emotional component of a memory. The amygdala seems to be spared structurally of changes related to age. Within the amygdala itself, however, Dulka et al. found that there was an impairment in the activity-dependent protein degradation which could underlie some functional deficits. Furthermore, because of its interconnectedness with the DLPFC and the hippocampus (both known to be affected in different ways by aging), we can assume that the amygdala shows age-related functional deficits, but may be important in strategies used by the aging brain to cope with structural and functional declines (of the areas with which it is linked).

Anterior Cingulate Cortex

The cingulate cortex is part of the limbic system (with the amygdala). It is situated at the border of the hemispheres, seen in a medial view of the brain (Figure 1). It surrounds the dorsal area of the corpus callosum (largest white matter tract that links both hemispheres together). The anterior cingulate cortex (ACC) receives information from the amygdala and the orbitofrontal cortex (another part of the limbic system). More specifically, the ACC provides the neural encoding of action-outcome learning. The ACC functions are varied and have been associated with value encoding, pain processing, performance analysis, emotional learning and motivation. It is clear from all these different functions that the ACC is involved in higher cognitive control for action and behaviour. According to Rolls et al., the ACC encodes the representation of value of a stimulus (whether a stimulus merits a response or not). It is related to emotion insofar as it integrates emotional input into the prediction of the reward or punishment of a stimulus. It provides information for emotional learning and motivation. The ACC has been shown to be less affected from declines seen in aging when compared to the posterior cingulate cortices. However, as ACC has deep connections with the frontal areas and the amygdala, this area is important when discussing aging brains and coping mechanisms.

Angular Gyrus

The angular gyrus (AG) is situated in the posterior part of the parietal lobe, near the temporal lobe (Figure 1). The AG receives little to no direct sensory information, reinforcing the idea of it being an associative area. It is connected to a variety of areas such as prefrontal cortices, the inferior frontal gyrus, temporal regions, the caudate and the hippocampus, as well as several others. The AG has been linked to various functions that include language processing (specifically semantic information), visual and somatosensory inputs, memory retrieval, spatial cognition and attention. It is also part of the default-mode network, a network that decreases in activation during goal-directed task but shows activations during thoughts unrelated to stimuli (also referred to in the literature as mind-wandering). There are many hypotheses as to the exact role of the AG in the mind-wandering process, but the majority of these mention the AG as a manipulator of conceptual knowledge and mental representation during daydreaming. According to some studies, the AG is involved in the reorientation of attention with respect to a stimulus that has a high salience. It may also have ramifications in the maintenance of attention and encoding salience of events in the environment. It plays a major role in combining spatial information with conceptual knowledge. Finally, as the AG has strong connections with the hippocampus, it is understandable that we see functions of the AG in memory retrieval (autobiographical and episodic) and may be important in the retrieval of memory in the context of a specific event. Declines in angular gyrus functions can be observed in the aging brain. There are significant reductions in the connections with the prefrontal areas and the hippocampus. In terms of specific reduction in grey matter volumes, it is not clearly defined (it is difficult to isolate the grey matter reductions to specific areas of the cortex such as the AG). However, the parietal cortex has not been shown to have a significant increase in decline as of the age of 60. It is important to remember that, as connections weaken in the brain with this area and coping mechanisms are put in place, some of these mechanisms will directly implicate the AG, which therefore would affect the overall behaviour of older adults and the strategies we can use to design healthy living environments for the elderly.

Insular Cortex

The insular cortex is only visible from a medial view of the brain as it is the cortical area situated inside the operculum (the extensions of the lobes generate a large fold, where the insula is created), within the lateral sulcus (Figure 1). The insula can be divided into two main regions, the anterior and posterior insula. The anterior insula is more significant in the context of this project because it has connections to the ACC, the frontal cortex, the orbitofrontal cortex and anterior temporal areas. In general, the insula mediates information about the internal states of the body with the external stimuli. It also controls the autonomic reactions to pain stimuli. More specifically, the dorsal anterior insula is involved in cognitive control processing (with connections to the prefrontal cortex, the ACC and parietal areas) and the ventral anterior insula is connected to limbic areas, connecting internal states of the body with emotional processing and expression. The role of the insula in emotional processing is the integration of the current internal state of the body with the exterior experience, linking emotion to experience and subjective feelings. Along with the ACC, amygdala and other subcortical regions, the insula is thought to be part of the salience network, a network that seems to activate when presented with a novel stimulus in a sea of same objects or stimuli that have been previously presented (the oddball effect).

Further information on the role of the insula in the salience network will be discussed when I talk about salience processing and the deficits in aging. According to Uddin et al., a general function of the insula as a whole is the combining of external information with emotional and internal states to coordinate different brain networks. This coordination of networks may be impacted by age, revealing attentional deficits and problems in focusing on relevant information. This idea will be further developed when I look at coping strategies in aging brains.

Decline in Function with Age

As we have just seen, a number of different areas of the brain are thought to be involved in the decline in brain function as we age. I cover here the differences and declines that occur in functional neural connections. These functional differences combined with structural differences start painting a picture of the overall changes in the brain of older people, which can then be used in architectural design.

Inhibitory Deficit Hypothesis

Inhibition of activity has been demonstrated to be an important part of the brain function. More specifically, the inhibitory deficit hypothesis (IDH) is based on the idea that inhibitory mechanisms are directly involved in attentional control which in turn regulates a variety of cognitive functions such as visual attention, memory, decision-making, etc. Inhibitory mechanisms regulate access to information early in the processing of information. Inhibition prevents irrelevant information from reaching the attention network and masking the relevant information in goal-oriented tasks. It also comes into play when some information that was initially deemed relevant must be deleted from the focus of the attention network or when information that was once relevant (maybe in a previous task) is subsequently deemed to be irrelevant for the current task. Finally, inhibition is used to suppress action or responses to stimuli in cases where the response time is very fast. These three main functions of inhibition in the brain with respect to the attentional network and salience are important as they can be related to attentional deficits in aging brains. In terms of accessing information, the inhibitory deficit hypothesis accounts for the reduced ability to overcome distraction due to the decline and reduction of inhibitory mechanisms. It is worth noting that one could alternatively explain these attentional deficits by an inability of older individuals to access the relevant information, but a number of studies have shown that the activation processes seem to stay constant over age.

A study by Stothart et al. analyzed the deficits in inhibitory processes using visual and auditory tasks. The study provides strong support for the IDH to explain problems in accessing relevant information as opposed to irrelevant information as well as ignoring irrelevant information. An increase in activation during the task was explained by the authors as being caused by additional processing required by older adults to reanalyze the stimulus to produce an appropriate reaction. Inhibitory deficits have been related to working memory age-related declines as well, where participants would produce more irrelevant information than relevant information, suggesting a deficit with the downregulated information that has become irrelevant. Studies have shown as well that inhibition has a larger role in context-dependent memory (episodic, working, etc.), rather than context-independent (semantic memory). Episodic memory refers to the memory of life events (including time, location, emotional reactions, etc.). Semantic memory refers to long-term memory of concepts that are not specific to each person, such as speech memory and conceptual facts about the world. Working memory is a short-term type of memory (temporary storage of information) related to decision-making and reasoning. Gazzaley et al. studied the inhibition effects in working memory tasks and concluded that there was an age-related decline in function for top-down (direct control of the brain over action, not related to a certain external stimulus) suppression of irrelevant information (which was previously discussed by Hasher et Zacks). This suggest that older adults have more trouble focusing on the relevant information for a distinct task and can become overwhelmed by other information which they cannot efficiently discard or ignore. Furthermore, the distraction (and thus loss of inhibition) may be different across different sensory modalities (components) and for situations with cross-modality stimuli. Cross-modal visual distraction may be much more present than for example auditory distraction.

Salience Processing

It has been suggested that one of the roles of the insula is to serve as a gateway of sorts, by processing signals and marking events/stimuli for further processing. In doing so, there is a process for discrimination between salient stimuli (and events) in contrast to non-salient ones. In this same paper, the authors suggest four main functions to the insula in the context of attentional salience (1) bottom-up processing information from the sensorial perception of an external stimulus) by the brain resulting (pr ; (2) focusing brain activity and allowing the switch between different brain networks such as the default mode network or the central executive network to access attention and working memory; (3) integrating information in both anterior and posterior insula to mediate the reactions to the salient events; and (4) maintaining strong connections to the motor system and therefore enabling If there is a decline in activity in the insula (particularly the anterior insula) in the aging brain, we can conclude that the salience processing of events would be affected in major ways.

A study performed by Wolpe et al. showed no significant effect of age on cerebellar deterioration but did show reduced grey matter in bilateral premotor and the lateral prefrontal cortex, which are areas of the brain that are related to adaptation in movement. Similar reductions were also seen in areas of the striatum. This reinforces the idea that there is an overall reduced capacity for adaptation in the aging brain. Furthermore, in this same study there was an increased level of hippocampal activity that could then suggest a coping mechanism in the brain, which would be age-dependent. However, as the hippocampus suffers age-related structural declines as well, the brain strategy to use this area to cope for the PFC may not be very efficient.

Goal Maintenance Theory

As mentioned previously, the PFC is related to higher-level executive function, which is directly correlated to executive attention. The Handbook of Aging and Cognition defines executive attention as “the ability to actively maintain goals and to use goal maintenance to suppress contextually inappropriate response tendencies”. The goal maintenance theory combines information about the role of the lateral PFC in executive attention as well as some of the deficits that are noticed in cognitive aging. According to this theory, the lateral PFC plays a critical role in cognitive control in order to sustain goals in working memory (task processing). Furthermore, the modulatory function of the PFC is critical in the outcome of an action and the processing of stimuli for specific tasks. The theory explains that, though the lateral PFC is not required for goal maintenance in the brain, as there are other mechanisms and networks that can function in a similar manner for short-term storage, the PFC is necessary in the maintenance of goal representation for task-specific processing, including planning actions and implementing the planned action. Finally, the goal maintenance theory tries to disentangle the role of the lateral PFC in attentional control in working memory. The PFC, according to this theory, would be involved in controlling the effects of distinct stimuli by biasing for responses that are connected to the goal representation. In other words, the PFC would either enhance the processing of relevant elements or inhibit irrelevant elements as a way of controlling the probability to act in one or another way and disregard dominant stimuli that are incongruent with the context as an outcome of the reduced function of dopaminergic networks and the lateral PFC. These declines are expressed through an inability to represent and maintain goal information over time and an inability to use context in the goal maintenance process.

Interestingly, Spaniol and Grady discuss context memory deficits and the PFC and their results seem to suggest that activation patterns in the PFC of older adults are distributed differently than in younger adults. Though these are similar results than seen in other studies, the authors reach a different conclusion. Rather than explaining the deficits through a decline in the PFC function, they conclude that there are reductions in the item to context representation. Therefore, though these theories are presented as being different, they stem from similar results in the literature and are just the interpretation of the results in various ways.

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