TESTING INHABITANT AGENCY IN INTERACTIVE ARCHITECTURE: A USER-CENTERED DESIGN AND RESEARCH APPROACH

by

Sara Costa Maia

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Abstract

This thesis assembled, tested and demonstrated an inhabitant-centered approach for research and design in Interactive Architecture (IA). It takes an initial step in addressing a critical gap in the field concerning the lack of empirical evidence to support IA’s fundamental claims, especially regarding inhabitant experience. The approach focused on investigating the question of whether inhabitant experience of interactive architecture (IA), presumably dependent on different models of interaction, could support one of the primordial rationales for the social relevance of IA. The rationale states that IA holds the potential to empower inhabitants in participating in the continuous formation of their environment. However, there is no published evidence to date to corroborate the statement’s validity. In fact, very little research has been done to date on inhabitant experience of interactive spaces in general, hindering our ability to justify its use or to properly ground design decisions. Therefore, this thesis presents an exploratory investigation, set to form the basis for the study of agency and empowerment in IA, and aiming to demonstrate an approach to tackle the problem of user-centered design and research in the field. An extensive literature review is thus conducted, from the concept of agency in the social sciences to an overview of the pertinent literature on interaction. Finally, an approach is demonstrated to generate empirical evidences regarding agency in IA. For that, an IA space is designed (comprehending four different models of interaction), assembled and tested, grounded on two user-centered design studies. The first study was an anticipated experience diary study, where 17 participants reported their imagined daily experience with an IA concept. The second study was a user experience survey where 30 participants inhabited and experienced the assembled IA space. This thesis successfully demonstrated a user centered approach for evaluating interaction in IA design concepts, especially with regard to the possibility of fulfilling one of IA’s many untested claims, making explicit the problems and opportunities observed along the process.
Preface

This dissertation is original, unpublished, independent work by the author, Sara Costa Maia.

The anticipate experience diary study reported in Chapter 8 was covered under the approval of UBC Behavioural Research Ethics Board, certificate number H15-02936.

The user experience study reported in Chapter 10 was covered under the approval of UBC Behavioural Research Ethics Board, certificate number H16-00621.
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To my parents.
PART ONE: THEORETICAL FOUNDATION
1. Introduction

1.1 The research problem

Interactive Architecture (IA) is a provocative field of investigation, with potentially disruptive impacts on the built environment. Nevertheless, the examination of its social relevance in literature is still incipient and ill-supported. In order to contribute towards an improvement of this scenario, I explore in my thesis one of the first sociopolitical arguments around the relevance of IA, namely inhabitant empowerment and agency, and test an approach to assess the argument’s plausibility.

Interactive Architecture (IA) can be broadly defined as an architectural setting computationally enabled to sense its environment and respond accordingly, in a dynamic feedback system. It is still a field that relates more closely to science fiction than to the mainstream production of architecture. Yet, its study spans over several decades and it appears to be gaining substantial momentum in the last few years, possibly due to the increasing availability of inexpensive and easy-to-use electronic components.

In a previous study (Costa Maia & Meyboom, 2015) I have argued that most recent research in IA are explained by a typical trend in technology development: they are a solution looking for a problem. That is, it seems suggestive that IA has not been fundamentally developed as a direct response to previously identified architectural or social problems and demands. Most investigations are instead rooted on new technology availability, with ad hoc discussion in the context of the built environment. Cedric Price (1966), whose projects are often regarded as precursory of IA explorations, comes to enquire: “technology is the answer... but what was the question?”.

Fifty years later, the question is still undefined. The precedence of technology availability over an established demand in architecture has caused the field of IA to develop disjointedly, with branches spreading towards a number of possible relevant concerns. In fact, the literature on IA abounds with arguments regarding the social importance of data-driven adaptable environments; but they are mostly speculative, unverified, and, above all, hardly convergent.

In the recent survey I conducted on peer-reviewed publications in the field, I found 27 completely distinct rationales for the importance of IA (Costa Maia & Meyboom 2015). They ranged from improving inhabitant’s experience of architecture or optimizing spatial organization (Jaskiewicz 2013);
to performing better environmentally and assisting us in better addressing an increasing shortage of resources, including space availability in urban cores (Kroner 1997); to giving autonomy to populations currently under-addressed by standard architectural settings, such as the elderly or people with disabilities\(^1\) (Meyboom et al. 2011). As Jaskiewicz (2013) points out, however, the potential extent of such societal impacts of IA is still undetermined.

The reason for this indeterminacy is, most saliently, the limited real-world application that IA has attained in time. But also, perhaps in an egg-or-chicken deadlock, it results from the lack of research to further understand and validate those assumptions on IA's social benefits\(^2\).

In fact, the research deficiency in IA goes beyond the lack of evidence to justify the extra investment represented by interactive features. Very few publications in the field report any empirical evidence at all against their hypotheses, and the vast majority of arguments around IA, especially the ones relating to inhabitants, is widely unsupported (Costa Maia & Meyboom 2015).

This is particularly problematic when considering IA’s intrinsic relation to interaction, use processes and user experience. Only in very rare occasions have IA researchers attempted to study users’ relationship with interactive systems empirically (e.g. Oh et al., 2014).

Arguments for the adoption of evidence-based, user centered design and research in IA exist, and are often referenced. Achten and Kopřiva (2010) highlight the inexistence of comprehensive design methods available that can support the design of interactive architecture. The authors then present a framework that incorporates user centered design elements from fields such as interaction design.

However, the application of extraneous methods to design and research in IA can reveal difficulties and complexities that must be addressed. This thesis took an important first step in assembling, testing and demonstrating an inhabitant-centered approach for research and design in the field.

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\(^{1}\)“Disabilities” are defined in comparison with a shared convention of what the standard human set of abilities are; terms such as “functional diversity” are better descriptors of the intended idea, yet they might not be immediately recognized by the reader.

\(^{2}\) A remarkable asynchrony between IA discourse and prototypical IA projects (Costa Maia & Meyboom 2015) also prevents the rationales presented in discourse to be put to empirical test, on top of the direct lack of academic research.
The use of established user-centered techniques from interaction design could provide us with the necessary empirical knowledge on IA's functioning and social relevance. However, the application of these techniques needed to be first tested in the context of IA for a number of reasons. For one, each available technique is usually only applicable to a narrow range of situations and must be employed accordingly (Vredenburg 2001). IA also presents its own challenges regarding inhabitant interaction and experience that were yet to be explored in a functional IA setup. Moreover, perhaps even more importantly, the particular development state that the field of IA finds itself in must be taken into account, for it determinates which are the most important questions that presently ask for answers.

This thesis studied how existing methods can be employed within the frameworks of IA, considering the specific challenges and purposes of architecture, and thus defining an appropriate approach for the field.

More specifically, the present work 1) employed a user-centered design approach to develop an IA apparatus, and 2) conducted a user-centered experience research to test empirically the plausibility of IA's claim regarding inhabitant agency. The goal of this thesis was to test and demonstrate a user centered approach for evaluating interaction in IA design concepts, especially with regard to the possibility of fulfilling one of IA's many untested claims. This goal was accomplished, making explicit the problems and opportunities in the process, and setting the basis for this kind of exploration in the field of IA.

1.2 Why inhabitant agency?

Each of the several rationales for IA presented in literature require further scrutiny. They address important topics, but they do not demonstrate, successfully or even tentatively, that IA is an adequate answer for them. Even environmental sustainability, which is the most explored and tested IA rationale to date (Costa Maia & Meyboom 2015), has had the validity of its arguments repeatedly challenged (Mcagher 2010). The critiques focus on IA’s need for machine-like maintenance as well as its machine-like lifespan, energy consumption and specialized operation, which may hinder the goal of sustainability in its very pursuit.

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3 The mechanical failure of some of the irises in the Institut du Monde Arabe is a favourite example of critics.
In my master’s thesis, I wish to explore a less prevalent rationale but one I deem highly pertinent to the domain of IA, i.e. inhabitant empowerment and agency, as it has been already declared. Its selection among others is justified by: 1) its critical participation in early debates in the field, 2) its conceptual relation with fundamental notions of IA, 3) a recent upsurge of interest in (architectural) production democratization, and 4) a personal interest in the political implications of the topic.

Before proceeding to explain each of these justifications, however, it is important to clarify the problem of inhabitant agency in IA, as it presents nuances that must be acknowledged.

First, the reader must not confuse inhabitant agency with architectural agency. Several authors have directly or indirectly discussed an idea of agency in IA that refers to architectural agency primarily (Calderon 2009, Adi & Roberts 2010, Jaskiewicz 2013): that is, the possibility of the architectural setting itself to actively provoke change in the world. In such instances, IA is typically approached as intelligent and/or autonomous machines. This is not the main concern of my research.

What I refer to as inhabitant agency is related to the inhabitant capabilities only: how the environment enables people to accomplish goals of their interest, especially regarding the conformation of the built environment itself. IA systems are thus the facilitators of inhabitant agency.

Negroponte (1975) is one of the main advocates for inhabitant agency in IA. Interestingly, his proposition is marked by architectural agency as well. For Negroponte (1975), the IA building is an intelligent agent which mediates inhabitant agency.

Even when isolating the concept of inhabitant agency from that of architectural agency, however, the concept can still be ambiguous. It is so because, as it will be later discussed, agency points towards something else, not itself. It is a value-based approach which depends on inhabitants' capability of achieving goals and high functioning, rather than relating to specific resources or methods (Johnstone 2007).

By definition, human agency is the underlying motif of any technology. We create technologies to achieve things we aim to do but that we couldn't achieve otherwise: we can't lift 10-ton weight alone, so we've built machines to do it for us; we can't add up a million numbers without making mistakes, so we've built a computer for that too (Minsky & Riecken 1994); furthermore, we can't comfortably inhabit certain locations due to environmental conditions, so we've built dwellings that protect us from environmental exposure. In IA, the discourse of inhabitant agency often loses focus amidst such
fundamental purposes of any technology. Jeng (2012), for instance, claims that IA, as well as other fields concerned with technology augmented environments, carry the expansion of human capabilities as a common objective.

Such hardly particular obviousness might be a reason why, despite comprising a rationale for IA, “expanding human capabilities” as a general feature has not been addressed to depth in any publication I have come across. The relevance of the subject only begins to appear when the problem is framed sufficiently specifically or in a contextual situation.

For instance, in computer sciences, user empowerment has mostly been addressed in relation to the environments that allow everyone to take advantage of technology (e.g. Clement, 1990), promoting democratization of access to technological capabilities (Blackwell, 2006).

In the field of IA, the broad critique of empowerment rests in how IA systems can limit rather than expand people's capabilities through hard encoded definitions (Cetkovic, 2012). Thus the discussion of empowerment becomes relevant in the perspective of assuring IA systems provide the capabilities that people are interested in.

At a more conceptual level, I argue that IA relates to inhabitant empowerment exactly in the fluidity of people's goals and needs (Costa Maia, Lima and Barros Neto., 2016), which is framed by the idea of agency as a value-based concept. As it will be later examined, IA discourse has long been centrally concerned with the possibility of IA to adapt to changing conditions (e.g. Eastman, 1971; Negroponte, 1975; Achten & Kopřiva 2010; Salim et al., 2012; Jaskiewicz, 2013). Thus, inhabitant empowerment in IA is not limited to the generic empowering component of any tool or technology. While these offer support to only a specific set of goals, IA would be able to adapt indefinitely, and continuously provide best spatial support to inhabitants' goals. This perspective on inhabitant empowerment through IA, however, is still not explored overtly in terms of agency.

The instance in which the idea of agency in architecture becomes a central and extensively studied subject is when a system intends to extend human capabilities towards influencing and participating in the formation of the built environment itself, rather than addressing external goals. That is, when the architecture is able to accommodate in itself the intention of inhabitants to influence its configuration. IA literature in this domain of agency is considerably more specific (e.g. Negroponte 1975), although still minuscule, and it is supported by a rich and vast debate in fields such as
participatory design and related areas. Thus, this agency of inhabitants towards their environment, towards having a say on the shaping of spaces that concern them, is the central subject of this thesis.

It was the idea of agency towards one's environment, specifically, that has marked the advent of IA as a field of study. IA is inexorably connected to matters of inhabitant agency and empowerment in architecture due to the context it originally bloomed from. This context, situated in the 1960s and 1970s, is characterized by two main processes: 1) the post-modern critique of design methods and mass housing, and 2) the development of cybernetics, which formed the basis of IA theory.

Habraken (1961) explains how well-intentioned modernist\(^4\) propositions for the problem of housing shortage was met with opposition by “the very quarters in whose interest the proposals were made”. People wanted to have freedom and autonomy regarding their dwellings, Habraken (1961) notes, *they wanted to have a say*.

When the iconic Design Participation conference was held in 1971, it accommodated well the initial debates regarding IA. Contributions from some of the most important pioneers of IA, such as Charles Eastman and Nicholas Negroponte, demonstrated the early connection between design participation and Interactive Architecture.

The easy match between the two fields is explained, to large extent, by IA's foundation in cybernetics. Gordon Pask, a main proponent of the second generation of cyberneticians, introduced the relevance of feedback, systems design and underspecification in architecture. Through systems thinking, IA would allow for buildings to become components of empowering environments, by integrating the human user as part of a larger control loop. Pask explicitly claimed that, in IA, “the designer is no longer conceived as the authoritative controller of the final product”; instead, “an environment should allow users to take a bottom up role in configuring their surroundings in a malleable way”. Haque (2007) also argued that applying Pask's ideas to architecture “is about designing tools that people themselves may use to construct – in the widest sense of the word – their environments and as a result build their own sense of agency”.

\(^4\) Habraken (1961) reports the conflict around mass housing in the Netherlands in 1918. It is a mistake to assume that Modernist ideas were undisputed throughout its decades of hegemony. What actually occurs in the post-modern surge is that the criticism becomes central to the discourse of architecture, although resistance had always been present.
Further developments concerning the idea of interactive participation in media studies also cemented the central concept of IA – interactivity – as intrinsically concerned with a shift in power towards the users and consumers of a content. Andrejevic (2009) explains the early advocacy for interactivity and co-creation in the discipline: “[w]hy were scholars so critical of top-down, one-way, centralized media industries? [...] The concern was not directed solely toward a particular set of media structures (top-down, one-way, etc.) so much as it was with the way in which these structures helped reproduce power and social relations”.

The same political perspective can be drawn for artifacts and buildings. In a well-known argument, Langdon Winner (1986) claimed that artifacts do have politics, as they are “ways of building order in our world”. Vardouli (2015) complements that “[h]ow artifacts order our world, and who controls, or should control, this ordering, are moral and political questions”.

It is therefore crucial to understand IA from its inherent potential of including the inhabitant in the definition of the forms they inhabit. As already argued, this was a main constituent topic of first debates around IA. However, interest in the problem faded after the 1970s. With the resurgence of IA in the 1990s due to the popularization of personal computers (Fox 2010), different rationales had occupied the central focus of the discipline. In my literature survey, no recent paper directly addresses inhabitant agency towards architecture in the context of IA. The concern only figures more centrally in related fields, such as open source architecture and technology mediated participatory design.

This thesis will shed new light on this rationale for the social relevance of IA and will demonstrate an approach to test its plausibility.

1.3 Thesis structure

This research intends to bring back the idea of an IA for inhabitant agency and empowerment, to make the bridge between existing but fragmented research, and to propose an approach to test empirically whether Interactive Architecture can indeed foster agency in inhabitants.

However, it can be anticipated that there is an exceptional lack of base research available to readily support my intents. This issue will be further discussed in chapter two, but it must be alluded to in

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5 Open Source Architecture refers to an architectural analogy for Free/Libre Open Source Software.
advance because the state-of-art of IA research and its many gaps has greatly shaped the overall approach to this thesis’ research problem.

Firstly and importantly, the research here presented must be considered widely exploratory. Additionally, due to little available information on inhabitants’ overall experience of IA, first hand research must be conducted to understand the broader scenario of user experience, before moving towards understanding the experience of agency specifically. Finally, due to the scarcity of built IA projects, this research will also need to design, develop and implement an instance of IA to enable the observation of inhabitant-IA interaction.

The research question guiding the entire process can be stated as follows:

*Is it possible to apply established methodologies from Interaction Design to Interactive Architecture in order to support evidence-based propositions in lieu of untested rationales? What are the appropriate ways to do that?*

Considering the specific interest on the rationale of inhabitant agency, the objectives of this study are the following:

1. To review existing research pertinent to the problem of inhabitant agency in IA, and to organize an appropriate background for the advancement of knowledge on the topic;

3. To propose and design an instance of IA and to ensure, through user-centered design processes, the suitability of the final design.

4. To prototype the interaction components of the IA instance, based on common IA descriptions, in order to enable empirical explorations of inhabitant experience.

5. To study and collect empirical evidence on inhabitant’s experience of the implemented IA project, with a focus on inhabitant agency and empowerment.

6. To report on the research approach, identifying main problems and opportunities, in order to compose a reference for future research.

The approach presented in thesis is not intended to arrive at new ways for fostering inhabitant empowerment through IA, although it will review existing strategies. Instead, it aims at investigating how well the existing conceptual body of IA, as is, affords one of its primordial arguments, namely inhabitant agency.
In order to ensure an unambiguous understanding of the discussion, I start by presenting definitions and overviews of critical concepts that define this study. Chapter 2 covers a thorough appreciation of the field of IA, by clarifying main concepts, presenting a condensed literature review, and discussing the relevant connections to the problem of inhabitant empowerment. Next, chapter 3 covers an overview of the concepts of human agency and empowerment from key theories to explore the subject: Capability theory, Self-determinacy theory and Self-efficacy theory. Related concepts are also explored.

After an understanding is established of the basic fields comprehended by this study, chapter 4 will concatenate existing research in neighbouring fields to IA which I believe are highly relevant to the problem at hand. Although the field of IA itself presents few related precedents, this can be found in areas such as participatory design, technological mediation, metadesign and end-user programming, apart from the early contributions of IA authors themselves. This chapter focuses on projects and open problems, reviewing a plethora of different ideas, rather than providing a structured examination of concepts.

In chapter 5, I explore the different components of interaction design and perception that might compete to foster inhabitant agency in IA. This chapter is a complementary counterpoint to the previous one. While chapter 4 is comprehensive, chapter 5 makes an argument for placing IA behaviour and interaction models in a central position in this research. Chapter 5 also builds upon examples presented in chapter 4, but with an instrumental interest. It elects, connects and explores the main concepts that will fundament the development of the IA apparatus design.

Chapters 1 to 5 compose the part one of this thesis, referred to as the theoretical foundation. The next chapters build upon the theoretical foundation to present a contextual approach to user-centered design and research in IA.

Chapter 6 defines the research problem to be addressed by the user-centred approach, and lists the specific research questions to frame the empirical study of inhabitant agency and experience of IA.

Chapter 7 describes the initial stages of a design exploration process for defining an interactive space concept.

Chapter 8 describes an anticipated experience diary study to explore the IA concept proposed in real-world scenarios. This user-centered design study revealed interesting information regarding the
potential user needs and user experience of IA inhabitants, as well as provided information to further
develop the IA concept.

Chapter 9 presents the finished design of the interactive space and its implementation inside Lasserre
Building, at UBC Vancouver campus. It also describes the process of prototyping interaction in an IA
setup.

Finally, chapter 10 describes the IA user experiment, where participants could try an actual interactive
space and report their overall experiences and their perceptions of agency.

All the next chapters are presented as described, building a trajectory from general background, to the
exploration of specific supporting knowledge for addressing the research problem, to the culminating
user-centered development and testing of an IA apparatus.
2. Interactive architecture

2.1 What I mean by interactive architecture in this thesis?

Interactive. Architecture. Each of these words are individually decisive in the definition of the concept of IA, and it seems difficult to escape the fate of introducing them one at a time.

Every architecture is interactive, because interactivity is a considerably broad concept. Waugh and Taylor (1995) explain that communication and interaction comprise wide variances, and that they can occur on a scale from reactive to proactive. Thus, simple artifacts, such as buildings, can passively react to a proactive human – the building having no internal goals or reference levels of its own – and still be considered in interaction with that human.

However, unsurprisingly, the field of interactive architecture refers to a very specific form of interaction and influence. Negroponte (1975) argues that for an environment to be considered responsive (or interactive, in the context of this research), it must take an active role and it must initiate, to a greater or lesser degree, changes “as a result and function of complex or simple computations”.

Thus, as a first approximation, IA may be defined in the following broad terms: architectural spaces that, enabled with computational technology, are able to understand in varying degrees their environment and occupants, and to provide context appropriate responses actively.

Such enabling technologies provide IA systems with three distinct abilities, which are highly dependent on ongoing, interrelated and yet distinct technological developments. Such abilities are the ones that enable architecture to “read” the environment, including its own state, and its use (through sensors); to process the data and formulate a response (through processors); and to execute a response (through effectors). Between each of these operations, there is a need for transfer of information (through wired or wireless communication).

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6 In their historic paper from 1943, with substantial repercussion in cybernetic thinking, Rosenblueth, Wiener and Bigelow had already separated active behaviour from passive behaviour, and subdivided active behaviour in purposeful (directed to a goal) and non-purposeful. This paper goes on in its categorization endeavour to describe a long hierarchy of behaviours, moving on to encompass complex, self-organizing and evolutionary systems, among others. For each system, a potentially different form of interaction is conceivable.
The forms of interaction in these systems vary, as well as the type of electronics adopted or the foci of examination. Different purposes are also explored, which has given rise to a sizeable “terminological inflation” (Glanville, 2001) around the field and the number of projects that fulfil the descriptions provided so far in this manuscript.

Apart from the term Interactive Architecture, some of the many domains tackling similar subjects in architecture are: Intelligent buildings, Automated Architecture, Reactive Architecture, Responsive Architecture, Transactive Architecture, Smart Architecture, Kinetic Architecture, Robotecture, Architectronics, Hybrid Spaces, among many others. These are by no means mutually exclusive domains. They not only overlap in large extent, as they also often lack clear limit of scope. Even in the case of Responsive and Interactive Architecture, the most recurrent terms among these mentioned, definitions were also found to be used inconsistently (Sara Maia & Meyboom 2015).

Given the aforementioned obstacle, it is unfeasible to rely on a consensual literature definition to establish a clear perimeter for the field of IA. Other researchers have come across this difficulty, often opting to coin their own terms as a solution (Lee 2012), and thus worsening the overall lack of terminological cohesion.

Some authors, however, especially the contemporary ones building upon cybernetics tradition (e.g. Park 2013), have adopted distinctions for IA that are well accepted in some circles consistently. Such distinctions focus mostly on the terms “Reactive Architecture”, “Responsive Architecture” and “Interactive Architecture”, and thus on the forms that communication occur. These terms are related to Sheizaf Rafaeli’s (1988) concepts of two way communication, reactive communication and full interactivity, respectively.

A responsive system is here defined as a system that responds to an environmental stimulus according to its nature and/or other available data. It distinguishes itself from purely reactive systems – such as a motion detector light switch – by the ability of responding not only to a trigger stimulus but also in accordance to context or other trigger-related information. As Negroponte (1975) would argue, the responses are a function of internal computations.

Interactive systems differ from responsive systems in the ability of the system to learn and/or build upon previous interactions. Therefore, as argued by Fox and Kemp (2009), Interactive Architecture
is defined as architecture in which the communication between the architectural components and the users is a dialogue with new messages being related to the previous ones.

In practice, it is not rare to see authors adopting these terms interchangeably. Jaskiewicz (2008) critique the lack of rigour:

“The notion of Interactive architecture is being commonly oversimplified, by being used to refer to buildings and built spaces which are capable of simple responsive adaptations and spatial customizations of various kinds. [...] only consequent replacement of linear logics that guide their behaviour with an ability to reason and learn [will result] in achieving true interactivity – creation of spaces which are able to maintain a dialogue with their users, not only responding to their demands, but pro-actively engaging themselves in all kinds of featured spatial activities”.

It makes sense that in order to meet IA requirements of adaptation to (unforeseen) changing contexts, as posed by many authors, IA needs to have intelligence, learn and adapt, and be part of the larger ecology, actively negotiating demands and – why not – resources. But importantly, this level of interactivity has not been achieved yet. Therefore, no IA exists to date to satisfy such requirements.

It is not immediately clear to me if an adherence to such terminological rigour would be beneficial to the exploration of the topic of inhabitant agency in IA. I argue that it would be rather counterproductive, for excluding from the debate a large number of projects and possibilities, without justified benefits. Thus, for the sole purpose of this research, I will consider herein the term “Interactive Architecture” as an umbrella for both responsive and interactive systems. Relevant publications that chose to frame their research with different terms, such as Eastman's (1971) “Adaptive-Conditional Architecture”, will also be considered as long as they fit the general understanding I propose for IA in this study.

So far, I expect to have provided an unambiguous understanding for what I mean by “interactive” (also conceived as the behavioural, techno-centric or procedural aspect of IA): environments that can change one or more of its features (i.e. provide physical responses), as a result of internal computations based on real-time data collected/entered from its inhabitants and environment.

The “architecture” part of the term “interactive architecture”, however, has still not been addressed. It is intriguing that IA authors are remarkably more concerned with the definition of “interactive” than
of “architecture” in the term, despite the fact that the latter definition is equally important for the configuration of the field. It is, however, somewhat common that authors separate the two spheres of the problem, i.e. interaction and architecture, exploring them individually (e.g. Henri Achten 2013, and Mikael Wiberg 2010).

If we look outside the field of Architecture, the definition of what the “architecture” in “interactive architecture” stands for becomes even more important. The IA domain falls on the border of different disciplines and, just across these borders, similar domains have emerged. For this reason, Yiannoudes (2010) proposes the understanding of these subjects (IA specifically) as ‘Marginal’ objects or, in other words, objects with no clear place, on the lines between categories.

From the side of Human-Computer Interaction (HCI), several studies that fit well inside our definition of “interactive” in IA exist in areas such as Ambient Intelligence (AmI), Ubiquitous Computing (UbiComp), Tangible Bits, and Smart Homes. Their fundamental difference from IA rests exactly on the definition of the “architecture” in the Interactive Architecture term.

For instance, it must be pointed out that research in AmI and related fields are often interested in the “incorporation of the physical world into the interaction between human being and computing devices” (Aarts & Encarnaçao 2006). IA, on the other hand, is interested in the incorporation of computing devices into the interaction between human being and built environment. This is a very fundamental difference, which has excluded several projects from this review. For IA, the architecture, or more broadly the physical environment, is not primarily the medium for other technologies; it is the end in itself.

Additionally, the “layers” of the built environment which fields such as smart homes are concerned with tend to be far more limited in quantity than the “layers” of interest to IA. Smart homes typically deal with a service layer that includes appliances, lighting and similar add-on systems. IA, on the other hand, may deal with a building's structure, skin, location, plan partition and layout, etc, apart from services and furniture. IA is concerned with the architectural space, rather than specific, detached elements.

But what is architecture after all? My argument so far is based upon the cognizance of concerns intrinsic to the field of architecture, although these concerns refer to no standard knowledge in
architectural theory. I present one broad definition for the reader who is unfamiliar with what might constitute the problem of architecture.

William Mitchel (1990) defines architecture as “the art of distinctions within the continuum of space”, a definition remarkably recurrent in post-modern theory. Hillier and Hanson (1984) explain that “buildings are not just objects, but transformations of space through objects”. According to the authors, architecture constitutes the spatial organization of everyday life, but it also represents social organization and culture through the physical configuration of forms.

So, after all, what do I mean by Interactive Architecture in this research? I mean environments that can change one or more of its features, the objective of which relates to the re-definition of architectural space, as a result of internal computations based on real-time data.

2.2 Cybernetics and the basis of interactive architecture theory

As it was already introduced, the discussions around IA are not new. They were born in the 1960s and were strongly grounded on a few critical concepts. It is argued that the development of Interactive Architecture originated from the introduction of cybernetics in architectural thinking during this period. A main proponent of this movement was Gordon Pask, who claimed that “architects design systems, not just buildings” (Pask 1969). With cybernetics, architecture is considered as part of a dynamic feedback system with users (Sterk 2006a), an idea that continues to offer the basis for our current understanding of IA.

Contemporary cybernetics began in the 1940s, despite its much older roots. Wiener (1961) define cybernetics as “the study of control and communication in the machine or in the animal”. In fact, the idea of cybernetics far surpasses the domain of artificial control systems in machines, with which it is most commonly associated presently.

Humberto Maturana, for instance, along with Francisco Varela, were biologists with lasting influence in architecture. They are well known for creating the term "autopoiesis", which originally refers to the nature of self-maintaining feedback mechanisms in living systems.
The concept of feedback is a central notion to cybernetics. From a Control Systems theory perspective, Goyal (2008, p. 8) defines feedback as follows: “feedback is a property of the system by which it permits the output to be compared with the reference input so that appropriate controlling action can be decided”.

The cybernetics notion of feedback is to this day the main theory behind a few human motor behaviours (Schomaker 1995) and other general goal-oriented behaviours. In psychology, for instance, theories such as the Feedback Intervention Theory (Kluger & DeNisi 1996), the goal setting theory (Latham & Locke 1991), and the control theory (Carver & Scheier 1981), argue that behaviour is regulated by comparisons to preexisting or intervention-provided goals or standards. As Karlin et al. (2004) explain:

[These theories] assert that behaviour is generally goal directed and that people use feedback to evaluate their behaviour in relation to their goals. When behaviour differs from the standard, this creates what they call a feedback-standard gap, and it is the desire to decrease this feedback-standard gap that mediates the effectiveness of feedback”.

For such a description, it becomes evident that feedback, and consequently cybernetics, are highly goal-oriented. An output cannot be fruitfully compared with a reference input for decision making if no internal goal or reference exists.

This understanding is very relevant to our discussion of inhabitant agency and empowerment in IA. As it will be later explained, agency can only be discussed in relation to a subject’s goals as well as matters of high level functioning.

When we talk about machines in cybernetic systems, however, the machine themselves are typically conceived with goals of their own, and the users are not the only party with goals. Thus, if IA is realized as a cybernetic system, the ways in which the inhabitants’ goals will influence and converge with IA’s goals must be the thing to determinate possible levels of empowerment. This idea will be further explored later on.

Pask (as quoted in Bateson 1991 and Haque 2007) explains the notion of goal-oriented machines:

“It seems to me that the notion of machine that was current in the course of the Industrial Revolution – and which we might have inherited – is a notion, essentially, of a machine without goal, it had no goal ‘of’, it had a goal ‘for’. And this gradually
developed into the notion of machines with goals ‘of’, like thermostats, which I might begin to object to because they might compete with me. Now we’ve got the notion of a machine with an underspecified goal, the system that evolves. This is a new notion, nothing like the notion of machines that was current in the Industrial Revolution, absolutely nothing like it. It is, if you like, a much more biological notion, maybe I’m wrong to call such a thing a machine; I gave that label to it because I like to realise things as artifacts, but you might not call the system a machine, you might call it something else.”

In the field of Interactive Architecture, different authors will conceive IA as different systems. IA may be conceived as a system with defined goals, or with user configurable/influenceable goals (e.g. Eastman 1971), which configures first-order cybernetic systems. IA may also be conceived with undefined and evolving goals (e.g. Sterk 2006). These systems comprise a learning system which nests the first, self-regulating it. They therefore configure second-order cybernetic systems. Higher-order systems, demonstrating characteristics such as autonomy and intelligence, are also part of the IA repertory (e.g. Negroponte 1975).

Authors with explicit “Paskian” references will most often base their explorations on the use of underspecified goals and second-order systems (e.g. Haque 2007, Jaskiewicz 2008). In fact, the common IA and cybernetic reference to “conversation” can only be addressed by machines capable of learning. The following images (Figure 1 and Figure 2), produced by Dubberly et al. (2009), describe the functioning of different systems based on cybernetic concepts.

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7 The term “second-order system” also refers to any higher-order system, regardless of the number of nested levels in the system.
Cybernetics is not the only influence on IA development, but it is most certainly the primordial one. Yet, several recent authors will completely disregard cybernetics and cybernetic concepts in their approach to the field. For this reason, I did not include the notions discussed in this section as integral...
part of IA definition, choosing instead to accept a broader understanding for what is being currently studied under the umbrella of interactive or responsive environments.

The following section will provide an overview of the field. It is my expectation that such an overview will assist in clarifying the trajectory of IA, the domains it has explored, the kind of research being developed and the challenges being approached. In sum, a definition for IA that goes beyond a demarcating statement or an aggregate of concepts.

2.3 A portrait of the old new territory of interactive environments

The very first explorations of technology-enhanced environments were speculative descriptions and representations. As early as 1914, Italian futurist Antonio Sant’Elia wrote of buildings “similar to a gigantic machine”, a vivid manifestation later curated by Conrads (1970) and others. The actual assembling of environments with embedded computing also preceeed the formation of IA as a body of exploration, and it might date back to Le Corbusier’s Phillips Pavilion for the 1958 Expo (Mayboom et al. 2011).

As already argued, however, it was only with the introduction of cybernetics in architecture that IA starts to emerge from a broader machine analogy. In 1967, for instance, Warren Brodey makes use of cybernetic concepts to explore a notion of intelligent environments. In 1969, Andrew Rabeneck wrote in the Architectural Design magazine about the use of cybernetic devices in automated architecture (Sterk 2006a). Rabeneck advocated for building technologies that were flexible, an agenda that was gaining particular strength in the period. Two years later (1971), Charles Eastman published his Adaptive-Conditional Architecture model, which reinforced the proposal that “feedback could be used to control an architecture that self-adjusts to fit the needs of users” (Sterk 2006a). Importantly, this concept of adaptability to users’ needs is perhaps the first social purpose explicitly justified by IA potentialities, a rationale that continues to permeate a significant number of IA arguments.

Around the same period, Nicholas Negroponte (1970) coins the term responsive architecture. Negroponte is concerned with the legitimacy of top-down design, and focuses his discourse around this critique. Negroponte's work have a great influence from Pask, which is manifested in both his writings and his projects with The Architecture Machine Group (Negroponte 1975).
I believe that Eastman and Negroponte represent the two different foci that emerged in the field of architecture from the incorporation of systems theory and computing developments during the late 1960's and early 1970's, with similar yet slightly contrasting approaches.

The first focus is illustrated by the writings of Charles Eastman. In 1971, when Eastman published his Adaptive-Conditional Architecture model, he presented schemes demonstrating that feedback could be used to control an architecture that self-adjusts to fit the needs of users. He argues that “the form of a well-designed physical environment reflects in detail the structure of the activities carried out within it”. Thus, he advocates for an architecture embedded with feedback mechanisms that allows for optimized environment-activity “fit”. For Eastman, “fit” is understood as the relative amount of effort required (in physical, psychological, social or economic terms) to carry out certain patterns of human activities in a particular environment. Thus it can be argued that Eastman’s approach is mostly concerned with the resulting configuration of a space and how well adapted it is for the needs and requirements of a certain user, engaged in a certain activity, in a certain moment of time.

Eastman (1971) was already concerned with the morality of designers imposing their values on the configuration of “fitness”, thus he stressed the importance of the inhabitant’s inputs in the calibration of the architectural machine. He had also considered the political aspects of spaces, by acknowledging that the activities and interests of different actors in space can be conflicting:

Because the level of support for different activities can change, the fit to be provided for controversial activities becomes a political issue and can be settled by political processes; the same issue may be revaluated and changed many times and the architect need not become the arbiter of social conflicts (Eastman, 1971).

In either case, however, his ultimate concern was with achieving the best possible fitness for the human inhabitant.

The second focus around cybernetics in architecture can be represented by Nicholas Negroponte. In his highly influential work, Negroponte had a more explicit political positioning than Eastman, and

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8The general steps necessary to construct the mechanisms described by Eastman are: (a) develop the input mechanism by which the user communicates his preference; (b) identify the critical variables that vary according to individual preference; (c) develop the appropriate control algorithm that alters outputs so as to reflect the inputs of the user.
was a great deal more concerned with processes and political structures than the objective qualities of a resulting space. In Soft Architecture Machine, from 1975, he consistently reaffirms the value of designing environments that are responsive to their inhabitants, in a process that increasingly removes the architect as a middleman. “The theory”, he says, addressing the use of computers in participatory design, “is that I can be the best architect for my needs, and I do not need a paternalistic human or mechanical architect to dictate my decisions” (Negroponte 1975)9.

Negroponte's approach might be diametrically opposite to a performative approach to architecture, which later became a common area of investigation in IA. Negroponte is concerned with architecture as a language, as meaning, a very different perspective that is highly dependent on context rather than objective parameters. “Rather than viewing the built environment as an efficient corpus of concrete, steel, and wood, let us consider it to be a language”, he suggests. “This would imply that my behavior within the built environment and the meaning I attach that environment are as important as (I really believe more important than) the physical thing itself” (Negroponte, 1975).

The work of Eastman, and especially the work of Negroponte, are important references for the present research. They will be continually evoked throughout this manuscript. However, these authors are far from the only ones discussing IA in its early days. Nor are their theoretical work the only significant type of work being conducted.

Notably, design speculation (or visionary architecture, as it may be called) became a very strong front in early IA development, since a practical exploration of IA could not be fully realized in built projects. With the Archigram group, speculative projects such as the Fun Palace, designed by Cedric Price (Figure 3) and assisted by Gordon Pask (Haque 2007), or the intriguing New Babylon by Constant Nieuwenhuys (1972), became icons of Interactive Architecture. In fact, it can be argued that some of the most relevant early IA works were speculative in nature. Currently, still, speculation is very lively in IA's discussions (e.g. Fox's 2010 description of the possible impact of future nanotechnology in IA).

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9 As it will be later analyzed, the removal of the “middleman” in the configuration of spaces starts to become less coherent when Negroponte starts to address intelligent architecture. In his proposals and considerations, Negroponte contradicts some of his previous arguments.
Cedric Price’s Generator is an example of an early practical project attempt, in opposition to the Fun Palace proposition, which had a more speculative nature. It is described in detail regarding hardware and software, and was designed to be the world’s first intelligent building (Santo 2012). However the project was never built. According to Sterk (2006b), in the mid 1970’s “architects struggled to build the computational and structural systems needed to implement their new architectures”, which led to an early hibernation of the field. It can also be argued that the upsurge of an anti-technological postmodern thinking was an important contributor to this discontinuation (Jaskiewicz 2013).

It is only in the 1990s that research around interactive spaces regains strength. This fact is due to the unfolding of personal computers, as well as the technological and economic feasibility to implement wireless networks, embedded computation, sensors and effectors (Fox 2010). Given the technological accessibility, the most relevant research in the field turned largely practical. Kas Oosterhuis (2003), for instance, opposed speculative approaches to IA, advocating that research should be “based on immediate practical possibilities”. His group, the Hyperbody, has produced a considerable amount of projects and research in the field, possibly more than any other contemporary group.

As already mentioned, this resurgence of IA was more diverse and less grounded on cybernetic concepts than it once was. It surfaced from a different context, with some researchers seeking to keep roots in the explorations from the 1960s/1970s, and some researchers describing brand new backgrounds.

Figure 3 - Fun Palace, by Cedric Price. Source: Price (1961).
In a recent survey I conducted on peer-reviewed publications in the field, I found 27 distinct rationales for IA (Costa Maia & Meyboom 2015), which start to describe the spectrum of IA research. The following list reproduces the micro-groups of rationales as identified by the aforementioned survey:

1. To provide assistance/support for inhabitants in performing activities.
2. To improve comfort/quality of living of inhabitants.
3. To adapt to changing needs of inhabitants.
4. To increase flexibility of architectural spaces.
5. To adapt to different people, or to maximize person-environmental fit.
6. To promote sustainability (ample).
7. To adapt to changing environmental conditions, or to improve environmental performance.
8. To minimize use or maximize rationalization of resources.
10. Spatial efficiency.
11. To deliver intended functionality/performance under varying conditions.
12. To improve performance (unspecific)
13. To find best fit formal solutions for both user activities and environmental changes.
14. To mediate the environment.
15. To adapt to changing social conditions.
16. To facilitate social connections.
17. To promote connection or engagement with the environment.
18. To promote new kinds of interaction between people and environment.
19. To promote new sensory/spatial/aesthetic experiences.
20. To fulfill possibilities and demands posed by technology.
21. To use architecture as an interface for digital information and virtual embodiment.
22. To promote inhabitant participation in construction/behaviour of environment.
23. To expand human capabilities.
24. To continue parametric modeling qualities into the built environment.

25. Paradigmatic shift towards performative architecture.


27. Potentially solve several contemporary problems (open).

The use of the rationales under the term “Interactive Architecture” and “Responsive Architecture” is illustrated in the figure below (Figure 4), adapted from Costa Maia and Meyboom (2015). It demonstrates that the rationales listed above present scattered use, without clear trends or strong prevalence.

*Figure 4 - Matrix of justifications found in publications addressing Interactive Architecture or Responsive Architecture (exact term). Adapted from Costa Maia and Meyboom (2015).*

Figure 4 illustrates objectively the lack of a unified stream responding for the title of “interactive architecture”, which has been repeatedly observed by others. Schnädelbach (2010), for instance,
Concerning design projects, notes that IA “ranges from designs for media facades to eco buildings, from responsive art installations to stage design”.

Apart from cheer rationales, several of these applied works and projects seem to provide an informing sample of what has been driving recent research in IA. A significant branch of experimental studies, for instance, is engaged in exploring formal capabilities of new materials, anticipating their large-scale application to buildings, but without clear architectural demand (e.g. Biloria, 2012; Parlac, 2013). This kind of research focuses on the “ways” possible for different “means”, as these terms are defined by Fox and Kemp (2009)10.

Other efforts resort in the proposition of intelligent and autonomous self-assembling components. Taro Narahara (2010) is one of these researchers, as he investigates and advocates for the design of “universal components that can tolerate technological, environmental, and circumstantial changes over time”. In this line of thought, “emergence” becomes one popular concept within IA.

In the theoretical background domain, researchers like Davis and colleagues (2011) intend to situate responsive architecture in the wider continuum of digital architecture by approaching responsive systems as an extension of parametric architecture. Parametric models, they argue, can adjust geometric models in response to real-time data, but must be “frozen” at a given configuration in order to be physically constructed. Responsive systems, in contrast, would allow a building to maintain its flexibility in face of changing data and parameters.11

Researchers and designers are also trying to explore new areas in the intersection of architecture and digital technology. Wiberg (2010) is one of these researchers concerned with the concept of media spaces, which “stretch and connect places”, in the “ongoing integration of digital technologies in our built environment”. Entertainment and art have also started sharing new borders with media and IA domains (e.g. Bongers 2002), often dissolving these distinctions.

10 According to the authors, the “ways” are the kinetic methods by which the system performs, including spatial actions such as folding, sliding, expanding, shrinking, and transforming. The “means” are “the impetus for actuation” and uses pneumatics, chemicals, magnetism, or electrical systems, among others.

11 Limitations that both parametric design and interactive architecture share can be quickly realized. Responsive and even interactive systems can only perform the procedures that have been predicted by system designers, limiting their capability of adapting to unforeseen conditions. Kilian (2006) points out the same issue with parametric models, which can only accommodate change when it is described within the current problem definition. A need for drastic problem reformulation that requires the algorithm to be altered might cause the parametric model to collapse.
Intelligence and animacy continue to be important topics within IA, which Santo (2012) explains as a “culturally-defined human tendency to challenge the boundaries between the animate and the inanimate or the human and machine”.

It is, however, around sustainability issues that recent developments in IA tend to gravitate. The most established area within IA application is that of systems designed for responding to environmental conditions and for ensuring energy efficiency. It is also perhaps the most demand-oriented niche in IA, nested in environmental sustainability requirements and pushed forward by a “green building” agenda. IA appears as an extra layer in the larger sustainable buildings scenario, by adding to energy intelligent systems the contribution of morphological adjustment and adaptive façade elements.

After "Sustainability and Environmental Conservation", a slight prevalence of "User-Centered Architecture" rationales can also be observed in the survey by Costa Maia and Meyboom (2015). As already discussed, this was a very fundamental concern that structured the emergence of IA as a field in the 1960s. The impossibility of conventional buildings to adapt to changing conditions, especially users' needs, is still very central to IA discourse (e.g. Achten & Kopriva 2010, Salim et al. 2012, Jaskiewicz 2013). However, these authors do not address this mismatch between inhabitants' changing goals and conventional unresponsive architecture in terms of empowerment.

Furthermore, despite the popular adoption of user-centred rationales for IA, the need for an actual understanding of the inhabitant-environment relation in IA spaces is significantly neglected. This is reflected in the types of research design found in the field.

Several of the published works in the recent years, specifically 41.6% of the peer-reviewed ones (Costa Maia & Meyboom 2015), are project-based research that strictly present IA prototypes and describe their behaviour (e.g. Goulthorpe et al., 2001; Narahara, 2010; Pan & Jeng, 2010; Biloria, 2012; Parlac, 2013). Their logic follows the architectural projects tradition of documenting formation process and final products. However, they are not typically concerned with providing rigorous performance results of such projects, especially regarding how users interact with and respond to the prototypes. Only 5.2% of the publications present any form of experimental research designs intended to support either theoretical propositions or design practices in the field (Costa Maia & Meyboom 2015).
This is an interesting gap, once observed the theoretical basis of IA, both old and new. For instance, Jaskiewicz (2013) attempts to translate the different worldviews of IA and traditional architecture in the following terms, among others:

Users are in the centre of the development and operation of any IA process, in opposition to traditional architecture where mostly designers, developers, engineers and stakeholders determine the spatial organization and qualities of the built environment.

However, contrary to this statement, users are commonly left out of the typical research in the field, being only referred to in IA's conceptual discourse. Case studies of a few prototypical installations and buildings also exist, but even these lack the focus on user experience. Achten and Kopřiva (2010) denounce this very problem, and propose the incorporation of HCI design methodologies as a solution.

As demonstrated by the current section of this manuscript, however, the topics addressed by IA are many and it is not the purpose of this thesis to explore each of them individually. Nevertheless, it is important to point out the weak figuration of agency among the rationales found in peer-reviewed publications. Even for the few authors that mention the issue, their advocacy is timid and their contributions towards the problem of agency in IA are barely significant. The content of the few publications that seem to support the idea of inhabitant agency will be discussed in later chapters.

Lastly, it must be mentioned that the survey by Costa Maia and Meyboom (2015) shows a steady increase in the number of publications addressing IA in the last decade. The expansion of the field is also illustrated by the main Computer Assisted Architectural Design (CAAD) conferences around the world: ACADIA 2013 had responsive, intelligent, interactive, and reconfigurable architecture as its main conference topic; and CAADRIA, eCAADe, SIGraDi and CAAD Futures have also consistently kept the topic of Interactive Architecture among their covered themes.

As the field gains more weight, and as we're once again faced with the enthusiasm of an imminent shift to the way architecture is conceived, the question remains: what is the real social relevance of IA? To what extent can we robustly support them with existing research? The answer will inevitably point to the urgent need of a better understanding of the potential social impacts of interactive environments. This thesis will endeavour to contribute to an improved understanding of at least one of IA's core rationales: that of inhabitant agency.
2.4 Under all the enthusiasm: a critique of interactive architecture

Since very early in the development of IA as a field, the description of a new world where buildings have evolved alongside a futuristic society to assume new functional and social roles has populated the imagination of architects. This expectation is justified by two reasons: first, because it is known that technology has the potential to catalyse profound cultural transformations; second, because IA carries the potential to cause unprecedented shift to buildings’ capabilities, which have otherwise evolved at a very conservative pace.

Several authors and researchers (e.g. Nieuwenhuys, 1972; Novak, 1996; Calderon, 2009) have focused on the understanding that IA (and digitally-driven architecture, more broadly) will further support the development of a new information age society, pushing forward new demands and requirements for architecture. It is an anticipatory view, given buildings have changed little since the introduction of those concepts.

The experience of Kas Oosterhuis sheds an interesting light on this topic. Oosterhuis has been a pioneer in the design of IA and, more specifically, in the development of intelligent, sentient spaces. In an interview with Greg Lynn (2014), Oosterhuis discusses the repercussion of his famous project Muscle NSA:

“We did many of those prototypes […]. In those days, we were still hoping for clients, but in the world outside the university, they didn't come. That was against my expectations. I actually thought that three to five years after you launched such concept, they would come. That didn't happen […]. It's sort of disappointing, but it's also a reality check. You have to work with the world around you”.

It does not take much to realize that IA has struggled to find its way from extravagant speculations and lab prototypes into the real world. We only need to look around to find that IA, after all these years, is not yet here. Perhaps, as already argued, the only niche where IA concepts may have had some taste of realization is that of climate-responsive architectures. It is possible that computer-enabled actuation of form has found in green buildings a significant real world demand and, most saliently, market application.
Energy efficiency is certainly a huge demand challenging architecture presently (although no robust evidence suggest IA to be a competitive response to it), but it is not the only one. Sustainability itself has been expanding to include a number of social, economic and technical aspects beyond energy and material optimization. In urban centres, which continue to attract ever-larger shares of the world population, living spaces are becoming increasingly limited resources. Permeable soil is reduced to a minimum. Public spaces and different urban zones continue to stage the struggle of contested spatialities. Architecture’s mandate to maximize well-being and efficiency often conflicts with needs for identity preservation and values of affective nature. Moreover, the critique of the paternalistic designer still finds its place in contemporary disputes, strengthened by new research findings (Vardouli 2015), and continues to call for further integration of the inhabitant in the formation of their environment. These, among many others, are already existing demands to the built environment whose solutions rest inconclusive. They are just some of the endeavours that have become part of architecture’s continued debates. Most importantly, they are current demands and endeavours that could potentially benefit from IA capabilities. However, despite the decades old academic investment on IA, they do not.

As already discussed, IA as a field initiated with the promise to promote buildings’ adaptability to users’ needs. This argument was continued in discourse, for it finds resonance with contemporary problems in architecture. However, it is a discussion that goes on feeding on wild declarations and no empirical evidence. Additionally, theoretical formulations and prototypical projects often resort to anticipatory demands altogether. Perhaps given an apparent failure to bring IA to mainstream building construction, research often chooses to focus on a future scenario where the necessary technology has become sufficiently mature and inexpensive to be ubiquitous. I argue, however, that there exists a significant distance between the future world we speculate on and the present trajectory of architecture.

The example of automation is rampant. Although autonomous systems started being introduced to architecture as early as the 19th century (e.g. elevators), they remained add-on systems that only influenced architecture collaterally. So far, it is reasonable to assume that interactive systems might follow a similar trajectory.

The current hype on smart environments, ubiquitous computing and the internet of things is satisfied by add-on ambient intelligence systems, not justifying the active (and expensive) participation of
spatial forms, which persists static. The popularity of interactive art has also mostly remained restricted to installations; and when applied to buildings, they hardly challenge the solidity of architecture, as they typically are composed of façade displays.

The trajectory so far thus suggests little integration: robotic tasks might be carried out by independent robotic components, digital information might be conveyed by increasingly sophisticated displays (including the possibility to register information onto real environments), intelligent assistance to daily life might be carried out by independent appliances and equipment, and architecture will remain the static enclosure within which all these activities and systems are organized socially and spatially.

The reason for this might be that all these systems’ purposes are not intrinsic to the main problems of architecture. Meanwhile, given the scale of architecture, comprehensive actuation of a building might remain uncompetitive and comparatively expensive. Add-on systems, with their own agendas, are typically the most logical and economical alternatives.

I argue that IA will be most relevant when dealing with intrinsic architectural problems. I stress on the need to focus on existing architectural demands, instead of searching for anticipatory demands that may well be fulfilled by other systems.

It is possible that societal transformations, as well as the degree of technology integration, will fundamentally shift the role and concerns of architecture. It is possible that matters such as sentience will become intrinsic to the problem of buildings and spaces in future. However, currently, architecture is faced with challenges much more familiar to architects and to the configuration of the built environment, which IA must be confronted with. So what is keeping IA from addressing these immediate demands?

For once, outstanding research gaps in the field have been systematically neglected. There are very limited efforts put towards addressing specific current demands in architecture and generating evidences regarding the adequacy of specific strategies towards specific problems.

I argue that academic work to provide support for decision-making in the design of such systems will become increasingly relevant and potentially determinant on the success of early projects. The lack of such supporting information might be a key reason for why IA is largely still limited to speculative manifestations, even several decades after the enthusiastic reception of the concept.
Therefore, in this research, I intend to establish a firm understanding of IA with regard to one specific problem, and test the adequacy of IA as a solution for that problem. Only through proper scrutiny and support through empirical evidence may we begin to understand the relevance of IA towards inhabitant agency, or any other rationale of interest.

The next section provides some initial questions regarding the suitability of IA to address the problem of inhabitant agency. The entire remainder of this manuscript is dedicated to the exploration of inhabitant agency as an existing, latent demand for architecture, as well as the ways in which IA may support such demand.

2.5 But is interactive architecture a good solution for increasing inhabitant agency and participation, after all?

In the introduction of this manuscript, I have already presented the main arguments for why Interactive Architecture is closely related to the problem of inhabitant agency. Else, although I argue that the demand for inhabitant agency in architecture exists, this is not commonly addressed in IA literature extensively. It is necessary to go to fields such as participatory design to find a well-laid basis of the problem and a rich research literature to build upon. Chapter 4 will explore this background in more detail.

It can be argued, however, that by considering IA as a tool that give inhabitants the chance to participate in the formation of the architectural spaces they occupy, IA can be included in the broader discussion of participatory design itself. As so, it inherits the pressing real-world demand that already exists for participatory design.

In this section, I do not intend to be overly redundant. I wish only to point the reader towards the existence of such demand, and synthesize the ways in which IA provides a compelling alternative to conventional participatory design methods. I also wish to highlight some current limitations of what is known and what has been done.

The following table (Table 1) compares IA settings as a new form of participatory design against conventional participatory design in architecture. It illustrates potential benefits of IA in addressing a
problem that conventional architecture has been trying to deal with for over five decades (e.g. Arnstein 1969), with varying levels of success.

Table 1 - Comparison of conventional methods of Participatory Design and Interactive Architecture in incorporating the inhabitant in the formation of their environment

<table>
<thead>
<tr>
<th>Conventional participatory design</th>
<th>Interactive Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporally constrained participation events</td>
<td>Continuous interaction and participation events</td>
</tr>
<tr>
<td>Addresses inhabitants’ requirements in a specific moment in time</td>
<td>Addresses evolving requirements continuously</td>
</tr>
<tr>
<td>Direct mediation of designer</td>
<td>Indirect mediation of designer</td>
</tr>
<tr>
<td>Limited to initial users</td>
<td>Continual integration of new users</td>
</tr>
<tr>
<td>People participating in the process might not be the party most affected by the design outcomes</td>
<td>Necessary exclusive responsiveness to the people occupying a space</td>
</tr>
<tr>
<td>Difficulty of anticipation of results</td>
<td>Real-time &amp; real-world feedback</td>
</tr>
<tr>
<td>Promotes sense of authorship and participation for people involved (e.g. head of family)</td>
<td>Promotes sense of authorship and participation to all inhabitants</td>
</tr>
</tbody>
</table>

Apart from these, it has been argued that the notion of interactivity in itself may enclose strong connection to questions of agency and empowerment. However, all of these arguments are based on conceptual definitions and theoretical speculations.

Despite the long review of IA in this chapter, it is hard to arrive at a technical description of IA behaviour and interaction because true IA systems, at a full architectural scale, are almost non-existent. IA can be prolifically described in terms of what it is can to accomplish (speculatively), but not how exactly it can accomplish, for lack of examples. Thus, at this point, any arguments put forth for IA are based on nothing more than conjecture. In fact, it can be argued that IA, in itself, is still little more than conjecture, or than an idea in very early development. An IA system must be defined still to
viable details, beyond what is typically available in IA literature, before any judgement can be made concerning its suitability as a response to participation demands.

This thesis will define and develop four possible IA systems, based on four models of interaction loosely described in IA literature (chapter 5). The designs (chapter 7), and especially the functional prototype of the interaction models (chapter 9), will allow for better-informed discussions on the systems’ suitability. However, in order to carry on any form of assessment, a proper understanding of inhabitant agency, as well as of any links between IA and agency, empowerment, interaction and mediation must be first discussed.

The next chapter will provide a better conceptual understanding of the terms agency and empowerment, which I have been repeatedly employing in my discourse so far. Only after this critical clarification, this thesis will move on to discuss related work and to establish specific interaction models for IA.

Ultimately, the question of whether Interactive Architecture is a good solution for increasing inhabitant agency and participation can only be answered by inhabitants who have truly experienced interactive spaces. This research will foster such opportunity and describe the approach to generate evidence-grounded responses to the matter.
3. An idea of agency and empowerment

3.1 What is agency?

The concept of agency can take very different connotations through different disciplines. There are also a number of fields and theories devoted primarily to the problem of agency, such as the Action theory in philosophy and the Capability theory in social sciences. In this thesis, I will adopt the notion developed by Capability theory and related approaches as the basis for my investigation.

Before explaining the concepts of interest to this research in the context I intend to use them, it is important to first explore some of the different definitions that are recurrent and relevant. They provide context and even assistance in clarifying the concept of agency we will later build upon.

In its most fundamental meaning, agency can be broadly defined as the capacity of an actor to act on the world.

According to Bruno Latour (2005), “anything that does modify a state of affairs by making a difference is an actor”. Thus, his criterion for identifying an agent is simply the detection of any difference that this agent may have caused in the course of some other agent’s action. Such difference does not need to be intentional nor meaningful.

Based on this definition, it is clear that agency, in its broad conception, is not limited to humans or even to living beings. Jaskiewicz (2013) follows this logic to argue that agency can be found in any type and any part of architecture:

> Once humans erect and begin to inhabit buildings (or any other architectural spaces), these buildings simultaneously begin to have a lasting effect on humans. [...] Consequently, it may be concluded that any kind of architectural component [...] can be treated as an agent.

To further clarify his argument, Jaskiewicz (2013) indicates that an agent's action may be extrinsic or intrinsic:

> To give an example, agency of a human being is normally considered to be a product of interactions between brain neurons intrinsic to that particular human. An agency of a chair that this human decides to sit on is extrinsic to that chair, as the chair
“makes” the human sit on it not through the processes occurring within the boundary of a “chair system”, but because of the human’s awareness of chair’s affordance and suggestion implied in that awareness that the chair is expected to be sat on.

What Jaskiewicz (2013) suggests next in his work, similarly to a few other authors, is that Interactive Architecture may also manifest intrinsic agency, hence creating a system of multi-agent interaction with inhabitants and possibly other buildings.

As it has been already discussed, this kind of architectural (intrinsic) agency is not a rare focus in IA (e.g. Calderon 2009, Adi & Roberts 2010). Since Negroponte (1975) and before, the perspective of autonomous, intelligent and acting buildings has been captivating the imaginary of architects.

When adopting a cybernetic perspective, the idea of architectural agency can be appreciated even more comprehensively. Assuming every IA system is expected to have some sort of internal goal, without which feedback structures are not conceivable, then every single IA system will also display some degree of intrinsic agency, even if it does not involve complete autonomy or intelligence. Thus, if every architecture or architectural element can manifest extrinsic agency (in Bruno Latour’s conception of the term), equivalently every IA setting (as understood for the purposes of the manuscript) can also manifest intrinsic agency.

The concept of agency continues to gain specific and distinct characteristics as it moves across fields and theories. In artificial intelligence, agency has continued to acquire considerably specific understandings in time, e.g. in Marvin Minsky’s (1988) work in the Society of Mind.

However, this thesis' focus is centred on human agency as explored by a defined set of theories. More particularly, I am interested in the social sciences' use of the term, which transcends a subject’s basic capability of action on the world and studies it with regard to the social-political structures in which it is inserted. How an IA apparatus may provide the spatial/environmental support to improve an inhabitant’s agency with regard to the processes that shape his/her built environment? This is the kind of question central to my research problem, although it might be influenced by other notions of agency that have been discussed so far. It is therefore a reasonably complex problem.

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12 See chapter 2.
It should be noticed, for instance, that even when considering human agency as simply the ability of a person to modify a state of affairs in the world, the subject is by no means a simple or well understood one. Metcalfe and colleagues (2010) present a number of factors known to affect a person’s metacognition of their agency, suggesting that our perception and appropriation of our own actions is rather inferential.

When the problem of human agency is posed in a social sciences perspective, more convoluted concepts also come into play, such as free will, autonomy, independence, values, moral. Note the presence of some of these concepts in Wikipedia’s page\textsuperscript{13} definition for agency in the social sciences: “agency is the capacity of individuals to act independently and to make their own free choices, i.e. ability to act on one's will”.

In the social sciences context, agency has become a core issue in several social movements, from feminism (e.g. Gill, 2007) to critical pedagogy (Freire, 1970). It has also permeated the discourse from several post-modern art movements to literary theory. The multiplicity and complexity of the concept prevent me from providing a review of agency that in any way approximate completeness. This is not the purpose of this chapter. Instead, I only seek to provide an idea of the vastness of current intellectual production that revolves around the concept of agency.

The next section will discuss the concept of human agency in the specific terms I intend to adopt it throughout this research.

3.2 Introduction to the theories of human agency and empowerment

In this thesis, I will adopt the concept of agency as it is proposed by the Capability theory. I will also follow Alkire's (2005) suggestion of making use of the Self-Efficacy theory and the Self-Determination theory as instrumental approaches to the concept of agency.

In my reference to the Capability theory, I refer most centrally to the work of the Nobel-prizewinning economist Amartya Sen. Sen’s definition of “human agency” stands for people’s freedom to act in pursuit of whatever goals or values they regard as important (Alkire 2005).

\textsuperscript{13} Wikipedia is an interesting reference in the context of this thesis, as it allows for a democratization of how knowledge is structured, presented and disseminated.
Johnstone (2007) explain that the capability approach regards agency as a person's “systematic ability to achieve high levels of functioning (which may or may not be realised in practice)”. He stresses that well-being, subjective satisfaction and access to resources should not be considered primarily in the understanding of agency, for “we do not value resources for their own sake, but always for some other reason, some type of activity or state that they enable us to achieve”. Thus, utility and resources are instrumental rather than constitutive to human agency. People's ability to reach their goals though such resources is what constitutes agency in the Capability theory.

Johnstone (2007) argues that, by focusing on the means and abilities to achieve goals, we can understand agency and capability irrespective of the conditions that individuals find themselves in:

Consider for instance, two women who both stay at home to raise their children, in one case having voluntarily left a job she enjoyed and in the other case having had no alternative owing to social norms. In terms of wellbeing alone, there may be no reason to conclude that one woman is better-off than the other (assuming they value their lives and their time with their children equally, and other factors being equal). A capability analysis looks very different, however, since one woman was able to make and act on a reasoned choice between two valued 'doings' while the other pursued the only available course of action and only accidentally ended up with a life that she valued. From a capability perspective, the former state is greatly to be preferred to the latter. Partly there is an underlying functionalism at work here: capability reflects systematic rather than accidental access to wellbeing, and therefore wellbeing is more likely to be sustainable and robust across time and context. (Johnstone 2007)

The example mentioned above not only clarifies the term, as it provides an argument for why agency is such an important quality, independently of other concepts such as wellbeing. Sen specifically asserts that “persons should enter the moral accounting by others not only as people whose well-being demands concern, but also as people whose responsible agency must be recognised” (Sen 1985).

This kind of argument also brings to question the architect's often paternalist role in designing environments and spatial configurations they deem best for the inhabitant. It also draws an immediate connection with IA, in IA's ability to offer inhabitants a sustained say in the design of space, thus potentially allowing systematic access to environmental wellbeing, rather than to a fixed solution.
The description of agency provided so far, however, is not an operational definition; in my research, I could not find operational definitions or measuring instruments to assess agency directly. Alkire (2005) suggests using autonomy (from Self-Determination Theory) or empowerment as a proxy for agency.

Empowerment, according to Alkire (2005), is an increase in certain kinds of agency that are deemed particularly instrumental to the situation at hand. According to the author, increases in empowerment would be reflected in increased agency (but not necessarily vice versa).

Johnstone (2007) argues that the concept of capabilities is equivalent to empowerment, since “they represent the power of the individual (or group) to avoid harms and pursue valued forms of functioning, including crucially the ability to make reasoned determinations of what is to be valued”. Competence may also be considered an equivalent concept to capability and empowerment, describing a person’s perception that they can do something.

The Self-Efficacy theory provides the basis to explore capability and competence operationally. This theory, often referred to as a theory of human agency (Bandura 2001), is concerned with “people’s belief in their capabilities to mobilise the motivation, cognitive resources, and courses of action needed to exercise control over given events” (Alkire 2005). However, it is argued that a self-perception of capability or competence may be, as already stated, rather equivalent to empowerment than to agency itself.

Autonomy, on its turn, is a construct that greatly approximates Sen’s concept of agency integrally (Alkire 2005). Autonomy is a concept from the Self-Determination Theory, and it measures people’s perception of their behaviour, condition and opportunities regarding how aligned these are with their own goals and values. Thus, autonomy is not equivalent to independency: a person can be autonomously dependent or autonomously independent, as these categories are orthogonal to one another.

It must be noted that Self-Determination Theory is not focused only in the concept of autonomy. Alkire (2005) explains that it describes three basic psychological needs that are pre-requisites to well-being: autonomy, competence, and relatedness. Furthermore, Self-Determination Theory intends to be predictive regarding the likelihood of a person to engage in a given activity.
Importantly, none of these concepts can be directly observed. They must be treated as latent variables, and instruments must be defined to assess the corresponding observable variables, e.g. self-reported levels. A literature survey could not identify validated instruments pertinent to agency and related concepts in the context of architecture.

It is very important that future research will refine and validate survey instruments for assessing human agency in Interactive Architecture. Due to time and other resources availability, it was not possible for the present research to validate the instruments it used in its assessments. This is not a critical problem in this thesis, since its main goal is to demonstrate a user-entered approach to IA. All studies presented here are pilot studies, meant to scrutinize their process and application. However, before these processes are applied to generate valid results, it will be necessary to first validate the instruments to assess human agency and related latent variables.

For reference, a few examples are listed below of questionnaire items intended to assess autonomy in different contexts, using Likert scales for levels of agreement to expressed statements. These contexts are (A) physical activity classes (Standage et al., 2005), (B) job satisfaction (Broeck et al., 2010), and (C) a virtual reality environment (Jung, 2011). These contexts are unrelated to architecture, but they provide a reference as to how to construct autonomy scales.

A1: I can decide which activities I want to practice.
A2: I have a say regarding what skills I want to practice
A3: I feel that I do physical exercises because I want to.
A4: I have to force myself to do the activities.
B1: I feel free to express my ideas and opinions in this job.
B2: I feel like I can be myself at my job.
B3: If I could choose, I would do things at work differently (R).
B4: The tasks I have to do at work are in line with what I really want to do.
B5: I feel free to do my job the way I think it could best be done.
C1: While I was in Second Life, I could choose freely what I wanted to do.
C2: I felt that I had a lot of control over my visiting experiences in Second Life.

Based on these references, we can propose the following items in the context of Interactive Architecture (IA):

IA1: I influenced changes to this interactive space because these changes interested me.

IA2: I felt restrained in this space to be a certain way or to do certain things (reversed).

IA3: If I could choose, I would have this space organized differently (reversed)

IA4: In this space, I often feel like I have to adapt to the designer’s own ideas on how to conduct certain activities (reverse)

IA5: The things I can do in/to this space are in line with what I really want to do here

IA6: I feel free to do my tasks in this space the way I think they could best be done.

IA7: I felt strong limitations to my decisions on how to do what I wanted/needed to do in the space (reversed).

As for the concept of competence or capability derived from the self-efficacy theory, a guide is available to instruct on the construction of adequate scales (Bandura 2006). Some of the instructions provided by Bandura (2006) are:

- Find a specific domain and list all contributing aspects.

- Challenges may be graded in different levels; provide sufficient gradations of difficulties built into the efficacy items to avoid ceiling effects.

- Don’t title the scale; the self-efficacy scale is identified by code number rather than by name.

Based on the instructions provided and on reference examples, we can then propose a set of items to measure perceived capability in interactive architecture. The scale below illustrates an example in the domain of adapting a space to one’s needs.

IA8-a: I can change the space to fit at least one of my needs

IA8-b: I can change the space to fit most of my needs
IA8-c: I can change the space to fit all of my needs

Having the adequate scales to assess human agency – or inhabitant agency, as it refers to the domain of architecture – and its proxies is a critical and necessary step in order to test the plausibility of the claim that IA can foster agency. The final construction, application and analysis of a few scales will be demonstrated in later chapters of this thesis. However, as already declared, these scales will need to be validated in future research.

Due to their proximity, the terms “agency”, “autonomy”, “empowerment” and “capability” might be used interchangeably in part one of this manuscript, as they will be adopted operationally in complement to one another. Other concepts, however, need to be differentiated. The following section will define important concepts that are not to be considered equivalent to agency.

3.3 Distinguishing agency from other concepts

Control is perhaps the most important concept to discuss in relation to IA. That is because an IA system may allow for a space or element to be controllable by inhabitants, to a greater or lesser extent, however this does not translate immediately to an increase of agency in the terms of Capability theory. If a person has control over things that are not meaningful to him/her, control may not reflect in increased agency. Yet, even if the control provided is not related to any purpose at hand, it may still promote inhabitant agency if it offers the inhabitant a state s/he values, e.g. the perception of being in control of something. Thus, the connection between control and agency will always be mediated by a person's goals and values.

Authorship is another relevant related concept. It can be broadly defined as a feeling of being credited for the qualities of a resulting outcome. It can be direct or indirect and, interestingly, it can be shared with other people. Authorship also differentiates itself from control as “I can feel some sense of authorship for the eventual effects of some of my actions, even when my actions are not the proximal causes of those effects” (Nahmias 2005). Control, even if indirect, should assume actions to be strict causes of effects.
Each of these terms is sufficiently complex to generate discussions over a number of papers, as they have. In the interest of brevity, I have only quickly introduced key concepts to facilitate their reference throughout this document.

In the next section, the relevance of agency and agency-related concepts in the realm of architecture will be concisely discussed.

3.4 Is the concept of human agency applicable to architecture?

The Capability theory, among others of the sort, is primarily concerned with social environments and issues. Sen's work, particularly, is developed around the problem of poverty and inequality in the world. Naturally, the question emerges: is it pertinent to carry this same discussion and concepts to the field of architecture?

Notably, a concern for agency and empowerment has not been limited in the literature to broad social problems. It has also been approached in relation to more specific processes, such as in the work by Füller and colleagues (2009) on internet-based co-creation activities. However, I have not come across any direct application of the theories discussed thus far (capabilities, self-determinacy and self-efficacy theories) in the context of architecture, although empowerment has been discussed more loosely in many opportunities (e.g. Comerio 1987).

Therefore, I must make an argument that these theories, and specifically the problem of agency, are highly pertinent to architecture. As already presented, Hillier and Hanson's (1984) definition of architecture states that architecture represents social organization and culture through the physical configuration of forms, thus introducing the close connection between social and architectural environments.

However, while in informal or vernacular settlements the incorporation of cultural and social organization into spatial structures is carried out as a collective enterprise, conducted by the very people in whose interest construction is made, in “modern” cities this process is often governed by gatekeepers. This is not to say that the gatekeepers are not part of the society, but they are hardly representative of the collective.
This kind of critique to traditional gatekeepers has been historically illustrated by the 20th century subversion of the so called high art or erudite art. It is also beautifully crafted in Terry Eagleton's (1996) arguments against the presumptuous activities of intellectuals and academics who elects which works are to be considered proper literature and which are not.

Regarding the formation of the built environment, gatekeepers may or may not be architects. However, if we analyze the architect-society relation specifically, research has been generating intriguing findings. For instance, Brown and Gifford (2001, p.93) found that “architects as a group cannot predict the public's aesthetic evaluations of architecture”. This reinforces the argument that architects are not representative of the broader community.

In contemporary cities, architecture still translates the modus operandi of an organization and/or society. However, as already argued, this translation is often not made by the same people who will inhabit the artifacts they compose. Nevertheless, these artifacts are embedded with control frameworks that regulate their use and occupation (Akrich 1992), building order into the world (Winner 1986).

In sum, architecture embeds the social structures that agency theorists are mostly concerned with. However, it typically reproduces these social structures through the mediation of designers. Thus, through this dynamics of incorporating and reproducing, architecture is a rich field to discuss agency in its social and political implications.

Without evoking agency specifically, Sean Wellesley-Miller (1971) describes the difference between vernacular and professionally designed environments, by considering them online and offline systems respectively. He explains:

A crucial feature of an on-line process is the importance of the time parameter, that requires all events to take place in real time. The formation of a socially-evoked environment is a time-dependent or ‘historical’ process, with all that this signifies in terms of involvement and meaning. This is something that tends to be completely absent from professionally designed environments as far as its future occupants are concerned. Consequently, even if the structure of the environment arrived at by each design process proved to be identical, the on-line process would almost certainly invest the environment with more ‘meaning’, simply because of the mode of its formation.
Wellesley-Miller’s (1971) description reaches a conclusion that is remarkably similar to the example presented by Johnstone (2007) on the two mothers, cited in section 3.2 of this manuscript. Agency is the mediator of how people perceive the outcomes of online and offline formation processes in Wellesley-Miller’s argument.

Furthermore, I will also present an example to support the argument that the architectural space is an arena of socio-political arrangements and conflicts, which greatly call for the pertinence of inhabitant agency. This example, by Malard (2002), is placed in a classroom environment, which Self-Determinacy academics have repeatedly explored, although not in an architectural context.

Malard (2002, p. 248) expose what she refers to as the physical-spatial manifestation of an event in the following instance (free translation):

For example, a lecture is the social form, the manner in which a group transmits knowledge institutionally; the room with student desks turned towards the person who will lecture is the physical form meaning "lecture hall" to the subjects that belong to such a culture. The spatialization of "lecture" is not only a layout. It has some meanings imprinted in it: all student desks are turned to the same side, suggesting that the attention of these people will be directed to that point; on the wall on that side there's a chalkboard, showing that written and graphic components are part of the activity; in front of the student desks and beside the chalkboard there's a desk where will sit the person to which all should be attentive; this desk is greater than the student desks and also occupies a greater relative area, which means that the person occupying it will be outstanding in that context; if there is someone in whom all others pay attention, that person is definitely more important than the others, in that group. Finally, a spatialization reveals not only the organizational structure of an activity but also the community power structure. As we have seen, in the spatial arrangement of the furniture and equipment we can "read" the lecture activity, with all its implications of pedagogy of the one who knows and the ones who learn.

The following image (Figure 5) illustrates two different “spatializations” of activities in classrooms. In the left one, the layout translates and endorses a dynamics where a lecturer knows and transmits his/her knowledge. In the right one, the layout translates and endorses a dynamics where everyone has something to add, and knowledge is shared collectively.
Figure 5 - two different “spatializations” of activities in classrooms: lecture (left) and discussion (right).

Of course, these symbolic relationships in space are culturally dependent and fluid. Regardless, however, the spatial manifestation of events is typically imposed in a top-down manner. In the classroom example, the students, who are the ones to benefit from the activities taking place, often do not find physical environments responsive to their goals and values. The teachers are also not typically involved in the architectural definition of the classroom either. The pedagogy imprinted in the space through design is someone else's: the school board, the architect, the gatekeepers.

This discussion will continue when relevant. In this section, it was my intention to present the arguments for why agency, as approached by the social sciences, is also very pertinent to architecture and design. I have also argued, in the previous chapter, that I believe IA to be an adequate field to explore the problem of inhabitant agency. Although it is by no means the only one, I anticipate that it does provide a number of advantages and potentialities when compared to conventional alternatives.

In the next chapter, I will discuss agency in the specific context of Interactive Architecture, presenting an initial framework to the approach of the topic.

3.5 Further considerations about agency and architecture

From a pragmatic standpoint, architecture is an infrastructure to support human activity. Thus, architecture provides the supporting environmental apparatus to allow people to perform their activities and pursue their needs and goals.
As such, architectural elements and space may be considered as resources in Capability theory. Johnstone (2007) makes a similar suggestion for technology in general and computers in particular. Although resources are not an end in themselves, they allow us to achieve goals and desired levels of functioning.

When considering IA, however, resources may be of two different kinds. They might be (1) related to space itself and what that space allows inhabitants to do in it, either physically or psychologically, or (2) related to the computational technology embedded in the space and how that technology might expand inhabitant's abilities. The first kind being more architectonical, whereas the second kind first requires an expansion of the role and scope of architecture as it is currently defined.

Johnstone (2007) builds upon philosophers of cognitive sciences to suggest that “technology is identified with tools and techniques by which we use the world to extend our powers”. These external powers, he argues, can work as important resources in achieving valued forms of functioning. The idea of empowerment through computers have been repeatedly discussed (e.g. Weller & Hartson 1993), although without a strong theoretical basis around agency.

In architecture related fields, this perspective seems to be the main focus of AmI and smart home systems. That is, to expand users capabilities in ways that the environment couldn't support before, through embedded technology. As suggested, IA may also be able to perform similar assistance (e.g. Adi & Roberts 2010).

If we focus on Eastman's notion of IA, however, the discussion of agency regarding this pragmatic view of architecture will be grounded in the capabilities related to more typical architecture scope. We can explore this by using the example of a person in a wheelchair.

Considering movement and circulation to be a critical activity to be supported by any space, wheelchair users may feel debilitated where space is constantly inaccessible and/or dangerous for them. On the contrary, they may feel empowered in a space with leveled accesses, wide doorways and adapted fixtures, where they can freely carry out their activities and approach their goals.

This example is not only about physical support, but it is also symbolical in its segregation. In that regard, our environment is designed to fit the needs and abilities of a majority group, while
compromising the needs and abilities of functional minority groups\textsuperscript{14}. Furthermore, architecture can be designed to support or demotivate a number of activities, both generally or for specific groups. These examples falls inside the implications of space configuration itself, their effect on people, and how they support or repress agency with regard to people's valued goals and states.

Although this discussion applies to architecture more broadly, it still supports a case for IA in increasing human agency. It is so because, in all cases mentioned, interactive architecture may allow for systematic rather than accidental access to wellbeing.

This discussion can be continued by integrating Negroponte’s (1975) discourse as a means of approach. He considered the access to responsive and meaningful built environments “as important as the right to good education”. By focusing on processes and their political implications, this approach shares grounds with the “Free/Libre, Open Source Software” movement in computer sciences. This movement exemplifies “both a new model of production and a social vision, building on the emancipatory potential of non-hierarchical and egalitarian production where individuals and collectives can access, modify and distribute the technologies they use” (Vardouli & Buechley 2014).

This approach is also more openly against the paternalistic role of architects and of architecture. It aligns with the already cited argument by Amartya Sen’s where he claims that “persons should enter the moral accounting by others not only as people whose well-being demands concern, but also as people whose responsible agency must be recognised” (Sen 1985).

Agency towards architecture, as advocated by Negroponte and many others, has been linked to several benefits that exceed the benefits of straightforward environmental fit. It is related to the development of place attachment, which in turn encourages use, promotes safety and boosts pro-environmental behaviour (Scannell & Gifford 2010). There are evidences it might result in higher satisfaction and valuation (Franke, Schreier and Kaiser, 2010). It might even lead to higher perceived group cohesiveness and job satisfaction in the workplace (Lee and Brand, 2005), as well as better

\textsuperscript{14} architecture can also be deliberately designed for subjugation, such as the Panopticon (Bentham 1843) and settlements in occupied territories (Segal and Weizman 2003), with mechanisms that go beyond physical constraints.
performance and favourable job attitudes (Gagné and Deci 2005). Finally, agency\textsuperscript{15} towards environmental conditions may reduce people’s discomfort with pain (Geer, Davison & Gatchel 1970), noise (Corah & Boffa 1970) and thermic levels (Paciuk, 1990) when compared to situations with identical levels of these stimuli but where no option of control is perceived.

Some of these benefits might be considered an indirect consequence of agency, intermediated by the role of authorship and control. I could not find any research accounting for the possible confluence of agency, control and authorship as confounding factors, or measuring their specific roles, in the results I refer to in this section.

In the next chapter, I discuss a number of precedents related to agency in architecture. They do not directly provide an improved understanding of the concept of agency because they were not directly developed around such concept. However they do bring about relevant, although fragmented, considerations, which will assist in a more complete understanding on the problem of human agency in Interactive Architecture.

\textsuperscript{15}These studies address perception of control, not agency; however, I am considering control towards discomforting situations to be a valued asset by people in general, so that increase in control would – in such situations – also determinate increase in agency.
4. Precedent discussions on inhabitant agency in architecture and in technology mediated spaces

4.1 Introduction

It is not possible to construct a helpful literature review focused solely on the problem of agency in Interactive Architecture. Most of the relevant background information that proceeds this discussion in the field, and approximates it in their concerns, have been already at least introduced. Despite a constant flirtation with the topic, an actual in depth exploration of the concept of agency in IA simply does not exist.

However, previous discussions related to the problem at hand abound in a variety of domains. They do not address agency in IA integrally, but they address some specific aspects pertinent to the topic, which can add valuable considerations to the overall discussion. Some specific applications in IA can also be explored in the light of agency, also adding to the topic.

This chapter will try to cover an extensive ground of fragmented investigations. I try to trace a thread connecting the different topics, but deviations should be expected. After this fragmented research is presented and important concepts highlighted, this manuscript will retake a more organized sequential construction towards the definition of applicable models of IA that can be experimentally tested with regard to human experience and human agency.

4.2 A historical overview: including the inhabitant in the loop of architectural design

In the discipline of Architecture, a discussion around any form of inhabitant agency can be most immediately retrieved in the field of participatory design. Several reviews exist of participatory design efforts that hold a fundamental concern for empowerment (e.g. Comerio 1987, Granath et al. 1996, Marschall 1998). It is therefore natural to start our broad exploration of inhabitant agency in this area.

As Comerio (1987) puts it,
The first principle of community [participatory] design is to recognize the rights of all citizens to have a voice in decisions that affect the places they inhabit, work, and linger in. Whatever the method, the goal has been to enable people to participate in their environment.

Participatory design is, in fact, the foremost field not only in architecture, but also in product, community and urban design to encompass and articulate a direct interest for including the inhabitant, user or citizen in the “loop” of space formation. It can be argued that Interactive Architecture, when conceived as an inhabitant-responsive space, may also be a form of participatory design. In fact, just like for Interactive Architecture, the 1960’s mark the debut of participatory design in mainstream debates, emerging from the same milieu of concerns and aspirations, as will be presented in this section.

Paul Davidoff’s “Advocacy and Pluralism in Planning”, from 1965, is one of the first works to introduce the concept of user participation in contemporary architecture and planning. The discussion is situated in a context of collapse of modernist utopias, a few years prior to the emblematic demolition of the Pruitt–Igoe housing complex.

Modernist project tradition is fiercely confronted in the 1960s’ and 1970’s. Empirical methods had their legitimacy questioned and refused (e.g. Friedman 1971), leading, initially, to a search for systematic rationalization of the design process. The most influential publication of the period was Christopher Alexander’s famous “Notes on the Synthesis of Form” (1964), which proposed a less arbitrary and more logical design process. His approach was known as design by science (Lawson 2005), however his methods were then, and are to this day, largely contested. Criticism on the reductive positivist character of the movement reoriented it towards a “systematic understanding of the elusive particularities of the human subject” (Vardouli 2014). Consequently, user participation becomes a central part of the design methods debate during the 1970s'. It is also in this context that cybernetics is well received to influence the understanding of the relation between buildings and people.

In 1971, the Design Research Society organized its first major international conference, titled “Design Participation”. The conference counted with the works of some of the most important precursors of IA, such as Eastman and Negroponte. In the conference proceedings, Nigel Cross argued for the

\[16\] For a broader analysis of the role of modernism and postmodernism in the discourse of consumer emancipation, refer to Firat and Venkatesh (1995).
blurring of the lines between “designer” and “user” as a potential pathway toward urban sustainability and a more democratic social order (Cross 1972 apud Vardouli 2014).

It is important to note, however, that despite the enthusiasm of its advocates, design participation has been a contradictory practice from its beginning:

Some architects view participation as a form of giving up, capitulating on the individual who knows less than the expert but is willing to live in his own mess. Others see it as the most promising and sensible, if not the only, approach to ensuring responsive physical environments. (Negroponte 1975)

After the two decades of post-modern reaction and design methods criticism, the topic of participatory design in architecture faded significantly, moving to become a relatively marginal research topic. Several of the participatory design's questionings in architecture were incorporated into contemporary thinking, but user involvement itself was mostly reduced to a form of user-centered design. It became a truism that we, as architects, design for people and we must understand the users' specific demands and needs, instead of aiming for universal principles. However, at least in conventional practice, the line between the “designer” and the “user” remained as rigid as ever, and the designer remained the expert entitled of making benevolent decisions based on users' best interest. This same form of user-centered design became the central approach in fields like HCI (see Norman 1988), although in a more systematic and scientifically grounded form than what is observed in mainstream architecture.

The following diagram, by Sanders and Stappers (2008) illustrates the landscape of user involvement approaches in design research (Figure 6).

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17 Despite its loss of significance in architectural design, participatory design methods and discourses kept considerable continual relevance in community design and planning.
In recent years, however, the discussion of participatory or “democratic” design has been regaining prevalence across design fields. In architecture, this has been happening under the support of market considerations\(^\text{18}\), new decision-making legitimacy debates, and cyber-cultural utopias of

\(^{18}\text{Vardouli (2015) points out “that research in open source and mass customization practices links user participation in design with better product development (von Hippel 2005 [apud Vardouli 2015]; Schacchi 2003 [apud Vardouli 2015]) and higher consumer satisfaction (Franke et al. 2010 [apud Vardouli 2015]; Anwar et al. 2011 [apud Vardouli 2015]).”}

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Figure 6 - The landscape of user involvement approaches in design research. Adapted from Sanders and Stappers (2008).
creative individualism (Vardouli 2015), apart from the influence of alien successful projects accomplished through collaborative participation and digital technologies, such as Wikipedia.

In a 2013 TED Talk, Alastair Parvin presents the WikiHouse project\(^{19}\) and talks about the shift from democratization of consumption towards democratization of production (Parvin 2013). Other researchers have also explored how emerging digital technology is changing supply driven architecture markets into more democratic demand driven ones (McMeel and Amor 2013).

As Vardouli (2015) puts it, the central hero of this liberation mythology associated with information technologies is the figure of the “empowered user,” portrayed as a “prosumer” (Toffler 1989), “designer-user” (Mackay et al. 2000), “innovation user” (von Hippel and Katz 2002), “produser” (Bruns 2008), or “maker” (Anderson 2012), to mention a few. Sanders and Stappers (2008) explain how the terminology “participatory design” in architecture has been obsessively replaced by “co-creation” and “co-design”.

Just as these terms might not mean the same thing for the same people, however, the idea of participatory design comprises, from its beginning, very different methods and views. Before continuing to discuss what it means for IA to be a form of co-creation, or exploring fundamental aspects regarding the issue, it is important to flag a main criticism regarding different approaches to participation.

User participation, especially when advocating for “democratization” or “empowerment”, is to be studied with advised criticism and even skepticism. In the apex of participatory design debates, Sherry Arnstein (1969) voiced one such criticism of the “participation” rhetoric in her widely cited article “A Ladder of Citizen Participation”. In the article, she devises typologies of citizen participation, with methods ranging from “non participation”, where experts make decisions on behalf of people and legitimate their choices with good intentions; through “tokenism”, where citizens’ voices are heard, but the final decisions are still made by experts; to “citizen power”, where participation or even control by citizens are effective, and true citizen participation may actually occur (Vardouli 2015).

\(^{19}\)The WikiHouse project is an open-source project in timber housing. Just like open-source software, however, the actual production and modification of WikiHouse components require an expertise inaccessible to the lay public. The public can only consume what experts create and develop.
The debate on whether it is possible, or to what extent it is possible, to have users taking part in the construction of their environments in a way that completely preserves their autonomy is a complex one. The debate can focus on a critique on methods (e.g. Arnstein 1969), or go all the way to questioning the concepts of autonomy or agency in themselves (Nahmias 2005). As Vardouli (2015) puts it: “Who designs? The “empowered” user? The tools and techniques that mediate the process? The designer of the tools and techniques?”

In the case of IA, the replacement of the human expert or the human intermediary for a non-human system does not invalidate the problem. In fact, the problem becomes more evident in the context of technology mediation. Section 4.2 will briefly review some perspectives regarding technology mediated participation. Next, section 4.3 will review a number of approaches, methods and systems for user empowerment in architectural design and IA-related fields, providing a critical analysis of these propositions. Lastly, section 4.4 presents considerations in the context of Interactive Architecture.

4.3 Technology mediated participation

Computers are often regarded as empowering tools not only for the expanded capabilities the technology brings about (e.g. Solomon, 1992, Mann 1998), but also for the significant ways that technology allows for social interaction, cooperation and political participation in the broader sense of the term (Clement 1990).

The idea of computers comprising the ultimate medium for participatory design was already present in early debates of the field. As Negroponte (1975) viewed it: “Ironically, the computer sciences, generally associated with the elite and often oppressive authorities, can provide to everyone a quality of architecture most closely approximated in indigenous architecture (architecture without architects).”

However, as Vardouli (2015) observes it, by replacing the human intermediary with a technological mediator, the early advocates for computer aided participatory design found themselves confronted with the question of technological intentionality. “To claim that artifacts have intentions is not to
animate them or cast them determinant, but to view them as active participants in mediating human perception and action” (Vardouli 2015).

Marshall Mcluhan, one of the most prominent contributors of the Toronto School of communication theory, claimed that every medium presents an inherent bias, a sort of “pre-information” that exists independently of what is being communicated (Mcluhan & Fiore 1967). As the title of his bestseller book prescribes, he argues “The Medium Is the Message”. Later, Mcluhan would extend the concept of bias to all and every technology, indicating that through a process of familiarization the bias ceases to be perceived, becoming an integral part of the environment; present but unnoticed (Vassão 2008).

Don Ihde (1979) and later Verbeek (2011) propose to classify technological mediation in two different types. The “hermeneutic” or “experience-oriented” type refers to the ways that technologies transform human perception of the world (through amplification and reduction). The “pragmatic” or “praxis-oriented” type refers to the ways in which humans act in the world (through invitation and inhibition) (Vardouli 2015).

These “hermeneutic” and “pragmatic” views of technological mediation suggest interesting relations to the ways in which agency or empowerment may be manifested in Interactive Architecture. These relations will be further explored in later chapters.

For the time being, the main objective of this section is to present the argument that no mediating technology will ever be neutral. This is an extensively studied topic, and I only intend to cover a few fundamental ideas that illuminate the current discussion. The interested reader can refer to the authors cited in this section for further information.

With regard to user interfaces, Weller & Hartson (1993) explains that there are constraints intrinsic to the human-tool interaction that limit what the user is likely to think of doing when manipulating the tool. Thus, the use of the technology transforms the user's problem-solving experience. Another important author, Ihde (1979, p. 56), suggests that “experienced use of technologies brings with it a simultaneous amplification of certain possibilities of experience while at the same time reducing others”. For Akrich (1992), designers inscribe their visions of the world, or “scripts”, in the technological artifact in the form of action and control frameworks: thus, the artifact affords amplification and reduction, invitation and inhibition according to the designer’s explicit intentions or underlying assumptions of the world.
More recently, interaction designers have started to capitalize on the inherent bias of technological artifacts. In the book “Persuasive technology: using computers to change what we think and do”, B. J. Fogg (2003) lays the basis for an expanding research area that by 2015 has already hold its 10th international conference. Persuasive technology, as the name suggests, investigates ways in which the design of technological artifacts can influence our perception of the world or of an entity in the world (hermeneutic type of mediation), as well as influence the decisions and actions we may take (pragmatic type of mediation).

Beyond technological mediation per se, we can start to explore the validity of empowering mechanisms that are necessarily biased. If a given Interactive Architecture will always be connected to the original designer's visions through control frameworks, would all sequent discussions on inhabitant empowerment be automatically inconsistent?

To answer this question, we must first go back to our definition of empowerment\textsuperscript{20}. Empowerment (or agency), as we have suggested, is related to one's ability to determine and achieve desired outcomes. From a Self-Determination Theory perspective, agency and empowerment may be viewed as how aligned a person's behaviour, condition and opportunities are with this person's own goals and values\textsuperscript{21}. Thus, complete control or complete independence are not necessary conditions to empowerment, unless a person deems such level of control or independence as a valued state. With regard to the biases or control frameworks embedded in the technological artifact, these may or may not be impediments to empowerment, dependent on how the user relate these limitations or augmentations with what he/she values and aspires.

Some authors have, in fact, argued that extraneous control mechanisms are important components of empowering systems (Duane & Finnegan 2003). The argument is based on the idea that control assists in the accomplishment of goals, helping users organize and manage their actions in an orderly fashion. Orlikowski (1991), in a moderate view, argues that control mechanisms are both enabling and constraining: “enabling in that they facilitate the coordinated action of individuals in the production process [...] , and constraining as they restrict the manner and outcomes of individuals’ actions”.

\textsuperscript{20} Different definitions of empowerment or even different epistemological stands would result in different answers.

\textsuperscript{21} This statement assumes (and this assumption has been made in chapter 2) that agency is equivalent to the Self-Determination Theory's notion of autonomy.
Simons (1995) comes to affirm that control and empowerment must be balanced, so that one doesn't lead to the failure of the other. In the study of workplaces, he identifies seven types of controls that must be in place to allow for effective user empowerment.

In a case study, Duane & Finnegan (2003) found that employees believe that control activities are significant empowering factors in the early stages of an intranet development process. In another case study, however, Orlikowski (1991) found relation between mechanisms of control, reinforcement of established forms of organization and centralized power in the implementation of a given information technology. It must be mentioned that these studies use a construct of empowerment that might be distinct from the one I have adopted in my research.

Lastly, it is also useful to confront the idea of interactivity as inherently empowering, following the same principle. The argument in favour of interactive technologies for empowerment certainly exists. Coleman (2003, apud Andrejevic 2009), for instance, states that “interactivity is political: it shifts control towards the receivers of messages and makes all representations of reality vulnerable to public challenge and disbelief”. Furthermore, interactivity presupposes user participation, even if to a small degree; it also presupposes that user becomes a key component of any outcome.

But authors like Andrejevic (2009) articulate an important critic of such view:

Claims that interactivity is inherently political or empowering, or that changes in social relations necessarily follow from the fact that audiences have become more active participants, are not cutting edge, avant-garde claims; instead they are relics of an outdated binary [...] To make an automatic association between interactive participation and democratic empowerment is intellectually complacent in the worst sense: by clinging to an outmoded set of associations it bypasses the conceptual work that might help imagine ways in which media practices could live up to the promise of democratic empowerment.

Such critiques of participation, responsiveness and interactivity must always be present when discussing empowerment in IA settings. For my review of existing approaches for sharing control with inhabitants, I will provide a critical appreciation of mediation issues whenever appropriate.
4.4 Main approaches for sharing control with inhabitants

As already suggested, user participation and empowerment in building or urban design/behaviour can take many forms. In this section, I will review several relevant works that have appeared to me as important to the discussion of Interactive Architecture.

4.4.1 Levels of control

The first of the relevant works that deserves note is the approach introduced by Nicholas J. Habraken (1961), which laid the basis for the concept of Open Building. In his early work, Habraken (1961) presented the problem of housing in the Netherlands and suggested the introduction of different levels of decision making concerning the built environment, each level with a different public. He initially defined three main decision-making levels: tissue, support and infill, respectively referring to the urban fabric, the base buildings and their fit-outs.

Habraken is not the only one to identify “levels” or “layers” concerning the composition of the built environment. Stewart Brand (1995), for instance, identifies layers specific to the problem of evolution and modification of buildings (Figure 7). The six S’s that compose his “Shearing Layers of Change” are: Site (eternal), Structure (30 to 300 years), Skin (20 years), Services (7-15 years), Space Plan (3 years), and Stuff (daily).

![Figure 7 - Shearing Layers of Change. Adapted from Brand (1995).](image)
The relevance of Habraken's work for the discussion of empowerment in Interactive Architecture, however, lies in the acknowledgement that the built environment, and its different levels, serves different groups of people in different scales and situations. Thus, empowerment in IA or any other form of architecture cannot be considered one-dimensionally.

Despite the great repercussion of Habaken's early publication, the clear formulation of his principle of levels was elaborated only more recently, in the book The Structure of The Ordinary: Form and Control in the Built Environment (Habraken & Teicher 1998). The image below presents an illustrative diagram extracted from that book (Figure 8).

Habraken and Teicher (1998) explain that the different levels of the built environment share asymmetrical relationships, with links of dominance and dependence. For instance, houses within a city block can be changed without any reorganization of the street network, but the inverse is not possible. Thus, “the higher-level configuration dominates the lower level; and the letter is dependent
on the former” (Habraken & Teicher 1998). In the case of same-level spaces, the environment is organized and subdivided by territory and its markers.

Importantly, Habraken and Teicher (2000) also introduce the idea of different levels of control. According to the authors, control distribution does not necessarily follow the distinction of environmental levels. An actor or group of actors may keep control of different environmental levels, while other actors might not have control over levels of which they are the primary users. It is also possible that some elements of the built environment belong to two different environmental and control levels.

It has been suggested that by aligning control levels and environmental levels, buildings can create conditions for responsibility and care (Cuperus 2001), fostering sentiments of belonging, ownership and tendance. This might be particularly achievable through IA.

The Open Building approach seeks to minimize the mutual interference of environmental elements, “combining the freedom of choice and dignity of individuals in their work places, dwellings and communities, with the ecological coherence and stability of culturally appropriate buildings and neighborhoods” (italic not original). As suggested by the diagram, the approach focuses on long term changes and stable configurations, which doesn't reflect IA’s penchants towards fluidity and real-time responses. Open Building also does not incorporate in its core the potentialities of computing technologies as mediators.

Computers, however, have been present since the early years of participatory design discussions, given the great enthusiasm stirred by computers development concomitant to the post-modern interest in the “user” of architecture. Some of these techno-centric proposals are discussed next.

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22 It must be noticed that higher-level configurations are devised based on preconceptions of lower-level configurations, though a relation of influence exist in this opposite direction. Furthermore, oftentimes, e.g. in case of informal settlements, the creation of higher-level settings are defined in a bottom-up approach through the organization of lower-level settings. However, it can be argued that the different possibilities of formation in the built environment does not challenge the relevance of the hierarchical structure.

23 http://open-building.org
4.4.2 Early computers and user empowerment through design

Negroponte (1975) presents one of the first examples of computer programs intended to engage with the lay user to generate an architectural design: ARCHIT, a system proposed by Rorick in 1971. Negroponte (1975), however, criticizes the program for centralizing the design process. In ARCHIT, the computer leads the conversation, asking questions and suggesting answers (“I would suggest this... don't you agree?”). Despite having the final word, the user is still highly conducted by the machine, cast by the format of interaction.

In the Speedwriter project, Yona Friedman denies this approach and intends to create a neutral machine, which allows for the user to freely express his/her own values and interests. Friedman (1975) explains the two ways in which he believes the problem of computer mediated participatory design can be considered:

The first one (which is the one designers today generally use) would be the one I label the “paternalist”. In the paternalist organization, it is the translator (designer, expert or computer) who establishes his own preferences and judgements, in the interest of a particular future user, after a learning period during which the translator learns the peculiar particularities of this future user. Thus the translator (in our specific case, the computer) would make some decisions for the future user, “with paternal benevolence”, leaving the entire risk of potential errors for this future user to cope with himself. (Friedman, 1975)

The second way I call “nonpaternalist”. In this case the translator makes no judgements or decisions and thus needs no learning period. It functions only as a sort of “speedwriter” denoting the tentative decisions of the future user and emitting a “warning” about expectable reactions of the real world upon each decision. In this case the learning period exists as well, but the learning is done by the future user, and it concerns the structural characteristics of the real world alone. (Friedman, 1975)

Friedman’s (1975) “nonpaternalist” proposal, the flatwriter, allowed users to select from a comprehensive repertoire of spatial configurations in order to modify a space. A warning system would provide feedback to inform users of the impact of their choices (Sterk 2006a). Thus, for Friedman, all control belonged to the user, who makes free and informed choices through a relatively sophisticated computer interface.
Vardouli (2015) argues that Friedman's use of technology as a neutral and disinterested support for design does not negate technological mediation. Instead, she claims that the apparatus “exhibited full awareness of the mediating role of technologies in human perception and action and aspired to create a protocol that will preserve the human as prime mover of a growing technological universe”. How well the flatwriter preserved the human as the “prime mover” or as a free agent, however, was left untested.

The nature of the system also indicates that Friedman did not intend a continual adaptation or negotiation of space. The system negates learning and makes no decisions for the user, which implies a cognitive demand each time a space modification is required. In fact, Friedman was not concerned with all the possibilities of intelligent or interactive buildings as continuously adapting spaces, but rather with a tool to allow lay users to become the architects of their own needs.

Negroponte (1975) worked on a machine with similar purposes as the flatwriter, which he called the “design amplifier”. However, Negroponte also went further and speculated on the possibility of intelligent buildings that could adapt themselves. In both propositions, Negroponte adopted a significantly opposite approach than Friedman's.

For Negroponte (1975), the computer is a surrogate self, and communication between human and machine would require the computer to build the necessary models of the user and apply them in context. The cybernetic concept of conversation permeated his propositions, as well as the growing body of machine intelligence literature at the time. The machine, in order to provide environmental responsiveness, would need to be imbued of intelligence and manifest understanding. Furthermore, Negroponte refused the use of regulatory control systems and believed that “absolute adaptivity would lead to terrible complacency.”

By conceiving the machine as a “good friend”, as a surrogate that contributes technical expertise to the user's design intentions, however, Negroponte (1975) acknowledged an inherent paradox. He questioned: “the machine intelligence necessary to support richness of dialogue will in fact be counterproductive to the participation because this same intelligence, like that of the human architect, would fall prey to the ills of translation ascribing meaning of its own? In other words, does the intelligence required to communicate contradict the notion of informed amplification?”. The author suggests that the computer should act as a good teacher who fosters an intellectual environment. However his considerations do not come to solve his paradox. In fact, by attempting to approximate
his machines to the human architect, Negroponte fails to present a compelling argument as to why he believes the machine could do a better job than a human architect interested in fostering the same ideal of user empowerment.

Negroponte (1975) acknowledges that the figure of the architect brings about important contributions during the design process which are not limited to designing, such as providing comfort and confidence to the user, or generating goals that the user could not think of himself. Could a computer provide that?, he asks. Both Negroponte and Friedman work on the assumption that the architect possesses a set of important knowledge and information; this can be extended to the possession of a critical architectural literacy, and the ability to question established ideas with regard to the production of the built environment. These are qualities that Negroponte's machines intend to also possess, along with biases and preconceptions that allow for understanding and conversation\textsuperscript{24}. When discussing intelligent environments that adapt themselves, he even gets to suggest that “maybe a house is a home only once it can appreciate your jokes”. In the end, the conflict between the arguments in favour of human-like intelligence and the arguments against the human architect in Negroponte's discourse is left unsolved\textsuperscript{25}.

Thus it is questionable to what extent, after criticizing the interference of human architects, Negroponte's propositions offer opportunities for increased responsiveness and empowerment. Vardouli (2015) suggests that responsiveness, in Negroponte's proposal, would emerge from a reflective process: “the user designed the environment that designed the user”. We can also argue that, just as was discussed in the previous section, the lack of complete control on the hand of the users does not negate empowerment.

Negroponte's speculations of intelligent, self-adapting buildings form a compelling set of possibilities that have greatly influenced the fields of Interactive and Responsive Architecture. However they are simply speculations, unlike the flatwriter or the design amplifier projects, which could be implemented

\textsuperscript{24} In a recent study, a team of researchers have found that even machine-learning algorithms intended for objective triage can present human-like unintentional bias, given how intelligence technology often seeks to mimic human learning (Feldman et al. 2015). In the case of Negroponte's propositions, however, preconceptions are not a problem to be eliminated, but it's rather an important component of conversation.

\textsuperscript{25} Although it would be easy to make an argument for the advantages of machine intelligence, including the constant availability required in self-adapting buildings, the conflict I point out does not refer to that. Instead, the conflict refers to the critique Negroponte presents of the human intelligence architect and how s/he interprets the users needs through hers/his own translation mechanisms.
and discussed to further detail. Sequent projects that aspired to empower the inhabitant towards the construction of their environment have also been closer to the flatwriter or design amplifier propositions, largely distancing from IA debates.

In the next sections I will explore what has been done in architectural research towards technology mediated participatory design, followed by an attempt of re-approximation to the problem of Interactive Architecture.

4.4.3 Some of recent proposals and the non-interactive architecture

Theodora Vardouli, who I have repeatedly cited in this chapter, has also proposed an apparatus for technology mediated participatory design. Vardouli and colleagues (2012) draw upon Friedman's flatwriter to propose the system called commonSense. The systems acquires real time data from a network of sensors, “while an online design engine visualizes the data, provides design recommendations in response to user habits or declared needs and desires, or allows users to develop their own design solutions through interfaces for different levels of design 'expertise’” (Vardouli et al 2012).

The project is theoretical and has not been implemented nor tested. However it presents two interesting contributions: first, the possibility of offering a varying number of design interfaces for varying levels of design expertise (a response to a problem that will be later discussed); and second, the conception of a platform where the public of a certain common space can negotiate it's configuration (a concern that has been largely explored by Habraken).

Other recent proposals of technology mediated participatory design exist. Lo and colleagues (2015), for instance, devised a computational platform to integrate occupants in the design process. Their system, instead of embedding built-in constrains to secure feasibility of the resulting design, chose to maintain the architects in the process, controlling the outcome. “The controls”, they say, “have to be optimized so that the collaboration of the occupants will not dictate the design too much, which might cause the design to lose control, yet will not be too constrained to the extent that participation is meaningless” (Lo et al. 2015). The system they propose uses both a bottom up and a top down approach at the same time; architects define the framework within which users can operate, so the
constraints aren't fixed but are pertinent to the situation at hand. Thus, instead of trying to neutralize the role of the mediator, Lo et al. (2015) embraces the need of a “control”.

The proposals by Vardouli et al. (2012), Lo et al. (2015) and many other recent works do not refer to the possibilities of Interactive Architecture. In the commonSense project, although data is collected in real-time, response and adaptation do not occur in real time. The data just feeds into a collaborative design dashboard, which can generate virtual proposals. In principle, the system does not execute them.

In the realm of installations, one particular work stands out for potentially addressing the interest of Interactive Architecture. The Reconfigurable House, by Adam Somlai-Fischer, Ai Hasegawa, Usman Haque and others, is a DIY, low tech, “open source” pavilion. It allows participants to wire new low-tech devices (e.g. cheap toys) and manipulate the source code. Although its transferability to the broader domain of architecture might be questioned, this project provides a rare investigation into the idea of an “open source” interactive space.

Nevertheless, the discussions of participatory (empowering) design, and self-adapting (intelligent) architecture seems to have diverged a long time ago. While the work of Negroponte and early cyberneticists seemed to connect the two ends, sequent developments of Interactive Architecture and technology mediated participatory design have been largely disassociated.

In order to study recent specific propositions and applications in the realm of interactive systems with an interest in user contribution, we need to look at neighbouring fields to Interactive Architecture, such as Interactive Arts and Smart Homes. I'll start by discussing a design approach that has been discussed with regard to continuous end-user software development as well as interactive arts: metadesign.

4.4.4 Metadesign

Metadesign was originally conceived in the field of Architecture, referring to a mechanism that articulates abstract design principles and parameters (van Onck 1965). The term was later employed

26 The mechanism sets the universe of possible configurations of a given object of design, from which the best variation can be selected. The Metadesign of van Onck (1965) greatly approximates some discussions of
as a social-cultural critique (Virilio 1995); as a framework for software design, in symbiosis with interactive arts (Fischer et al. 2006); and again in architecture in reference to the software design framework (Giaccardi 2005). In this section, I will review Metadesign as the framework studied by Fischer, Giaccardi and others from the Center for LifeLong Learning and Design, because I believe this approach is the one that explicitly suggests a bridge with Interactive Architecture, as it does with Interactive Arts.

Meta-design, in this sense, is a conceptual framework which defines and creates the means for users to become co-designers of a system throughout the whole existence of the system. Thus, Metadesign is a step forward towards interactive architecture and away from conventional participatory strategies, since it is intended as a continual process and not limited to a one-off stage of design.

The idea is that even if the system is adequately designed at the design stage, it still needs to be evolvable in order to fit unanticipated needs, new subjects and emergent contexts. Metadesign proposes the creation of open systems which allow for modifications whenever required, providing the users with opportunities, tools, and social reward structures to extend the system to fit their needs (Fischer & Giaccardi 2006).

Fischer and Giaccardi (2006) warns, however, that “the goal of making systems modifiable and evolvable by users does not imply transferring the responsibility of good system design to the user”. It only implies that the system must be designed for evolution, and that this evolution, to a certain extent, will be carried out by users without requiring the assistance of the designer. In this sense, the authors seem to acknowledge that the original system designer retains certain control over what the end-user may do or perceive, through control frameworks inscribed in the system infrastructure (see Akrich 1992)

However, the extent to which Fischer or Giaccardi consciously recognize the relation between what end-users will later develop and the original system infrastructure is unclear. Giaccardi (2005) claims that, in Metadesign, content and context are separated, and that context alone is to be dealt by Metadesign. Vassão (2008) critiques that this immiscibility between form and content appears to be *sine qua non* condition to Giaccardi's approach, rendering it contradictory.

what is currently referred to as parametric design. It must be noted, however, van Onck's critique of style as a main driver of design, a frequent characteristic of contemporary parametric design.
Regardless of their understanding of the relations between the system infrastructure (or context) and future user design, Fischer and Giaccardi (2006) explicitly mention concerns for user empowerment and advocates for users to contribute towards the evolution of a system with their own visions and objectives. However, the authors do not develop this argument further, rather focusing on technical aspects of the framework.

Fischer and Giaccardi (2006) propose that Metadesing must be undertaken through what they call “underdesign”: the practice of designing environments that allow the “owners of problems” to create their own solutions at use time, instead of offering a complete set of solutions for use. The method they suggest for the development of the underdesigned system is the seeding, evolutionary growth, and rescoring (SER) model. The model is based on the postulate that “systems that evolve over a sustained time span must continually alternate between periods of activity and unplanned evolutions and periods of deliberate (re)structuring and enhancement” (Fischer & Giaccardi 2006).

One of the main technical problem observed by the authors in the process refers to the inverse relation of a design tool's flexibility and its learning difficulty for the “owner of problems”. For instance, general-purpose programming languages (e.g. C++) offer great flexibility and can represent any problem that computers may be employed to solve; however they are largely inaccessible to the typical architectural occupant, because they provide the incorrect level of representation for most problems (Shaw 1989 apud Fischer & Giaccardi 2006). On the other hand, domain-specific systems, such as The Sims' Construction Mode (Electronic-Arts), provide accessible support for certain problems, but the user is limited by the defined boundaries of the tool as a closed system.

This is an issue that Vardouli et al. (2012) have addressed in their proposition, as already presented. They suggest offering the user a range of different interfaces for different levels of expertise or interest. Not Fischer nor Giaccardi, in any of the publications I have read, come to suggest a fluid use of different expertise interfaces. However, they acknowledge that a same user will assume different roles during the use and development stages of a system, depending on the situation at hand, these roles being “passive user”, “power user”, “domain designer”, etc, even if the user is an expert developer.

Furthermore, Metadesign implies a process of co-adaptivity: both the software artifact and the human subject evolve and move beyond their original states. Therefore, Metadesign sustains an interactive
feedback of information between technological and human systems (Fischer & Giaccardi 2006), resembling the dynamics discussed by cybernetics and Interactive Architecture.

In fact, several of the issues discussed so far regarding Metadesign are relevant to IA. Underdesign, for instance, is a strategy that has been applied to architecture with similar interests to its employment in Metadesign, such as in the famous Quinta Monroy social housing project, in Chile, by Elemental.

![AS DELIVERED frontal view](image1)

![AFTER OCCUPATION frontal view](image2)

*Figure 9 – Illustration of the Quinta Monroy social housing project by Elemental. On the left, the original design as it was build and delivered and, on the right, the building after modifications and extensions executed by inhabitants.*

When an IA system is designed to encourage users to articulate their own spaces, underdesign might also be a pertinent strategy. However, in adopting underdesign, IA must also deal with its questions, such as the way in which the provided infrastructure (context) defines a design space and indirectly influences what will be considered by users.

The SER model, on the other hand, establishes an explicit control framework. It anticipates the need of deliberate structuring or organization of contributions, which might be assured by a group of experts responsible for the stability of the overall project. It also describes a linear trajectory of evolution to the system, which might be appropriate to an open source software project, but not as much to all the universe of possibilities of Interactive Architecture. In IA, while a linear evolution might be possible, it is expected that complete deconstruction and reconfiguration of spaces and behaviours should also be supported in different strategies, as well as regressions and isolated settings.

The flexibility versus difficulty issue of the communication medium is also of great interest to IA. However, the importance of the subject requires it to be discussed separately in its own chapter,
alongside a broader discussion on the matter of interaction. The following chapter will address interaction more centrally.

To finalize the review of existing approaches in occupant participation, I will present implemented projects in fields that most closely approximate the technical problems of Interactive Architecture, such as Ambient Intelligence.

4.4.5 Smart homes, context-aware applications and end-user development

When moving closer to the technical problem of IA, in domains such as smart homes, intelligent environments, Ambient Intelligence (AmI) and Ubiquitous Computing (UbiComp), the matter of user participation tends to have a more pragmatic approach, focused on the design and implementation of specific systems.

I refer to a shared technical problem because I believe these fields hold significant broader distinctions among themselves that must be acknowledged. In identifying the distinctions, it becomes easier to understand the potential difficulties of transposing findings and concepts between fields. The reader must refer to section 2.1 for clarification.

In this section, I focus mostly on studies of context-aware applications and end-user programming from domains external to IA. Noteworthy, although the word “user empowerment” is mentioned in the papers I reviewed from these fields, the matter of empowerment itself is not discussed. Usually, these papers include the user in the loop for a matter of usability, because other methods in context-aware applications are not sufficient to assure satisfactory performances.

Context awareness is an important technical problem in spatial responsive systems for self-evident reasons: these systems respond or adapt to contexts of use, and no unstructured need, requirement or activity emerge detached from context.

Most, if not all, of IA descriptions in literature underlie the need for an IA system to be context-aware. For instance, Biloria (2010) talks about the optimal augmentation of morphologies in accordance with contextual variations. In discussing the possibilities for IA, Fox and Kemp (2009) state that “[t]here is great potential for dynamic architecture that arises from understanding what a space or object is currently doing and how it can aid in promoting or accommodating a specific task”.

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The discourse of a spontaneous adaptation of IA to changing personal, social and environmental demands is notably recurrent (e.g. Achten & Kopřiva 2010, Cetkovic 2012, Salim et al. 2012), presupposing the IA system can understand and adequately interpret these changing demands.

However, the exploration of these possibilities in IA remain highly speculative or limited to simplistic systems. Therefore, authors in IA do not usually deal with the technical problems of context-awareness. These are problems that are much more often addressed in HCI, AmI, UbiComp and smart homes literature.

Dey et al. (2004) assert that developers currently have two options for developing a context-aware application. The first one is to build a rule-based system, thus predefining specific sets of behaviours dependent on certain data readings. The second option is to build a recognition-based system (Dey et al. 2004), also referred to as an inference engine (Zhang & Brügge 2004), which uses machine learning and intelligence to interpret data and infer the context.

As Zhang and Brügge (2004) point out, the problem with the rule-based system is that the designer cannot anticipate all situations of use, and the system cannot handle complex or unpredictable situations that could not be described with well-specified rules. On the other hand, recognition-based system tend to be cumbersome. Dey et al. (2004) explain that recognizers often need to be handcrafted over a period of days, weeks or even months in an attempt to optimize recognition performance. Zhang and Brügge (2004) also argues that, to date, there is no ascertained way for a system to infer a correct contextual state just by collecting sensor information. Davidoff et al. (2006) explain the difficulties in mapping people' activities and routines to such systems. More recent research demonstrate that inferring context remains a challenging problem (Shafti et al. 2013). In both cases, rule-based and recognition-based systems, the approaches fail to achieve short or long term compatibility with the end-users’ expectations (Greenberg 2001).

Zhang and Brügge (2004) argue that the only feasible alternative to date for a system to agree with the users’ expectations is to have the user program the system behaviour him/herself. Therefore, the matter of user control, if not user empowerment, comes into play as a pragmatic response to the current insufficiency of context-recognition systems.

In this sense, end user development (EUD) becomes a relevant field of study in spatial responsive systems, including Interactive Architecture. EUD, which in a broad definition may comprise end-user
programming, end-user software development, customization of digital technologies, among others, has been an important research issue in HCI since the early 1990s (e.g. Henderson & Kyng, 1992), and possibly going back even further over a decade (Tetteroo & Markopoulos 2015).

One interesting EUD system in the field of Intelligent Environments is part of the Intelligent Room Project (Gajos et al. 2002). This project uses a rule-based strategy for context awareness and behaviour, allowing users to create and feed their own rules and goals into the system.

The Intelligent Room Project is composed of three distinct systems: Rascal, ReBa and Alfred. Rascal is a framework for goal-directed self-adaptivity. The system works with a varying list of goals which it plans for achieving, considering the resources needed to implement the plans and the known user preferences. Since each goal may be satisfied by multiple plans (e.g. a room can be made brighter by either turning on the lights or opening the window blinds), Rascal can adapt the system behaviour to varying circumstances by selecting a plan that best accommodates other goals in the system, thus being appropriate to context. ReBa, the next system, is the reactive component of the Intelligent Room Project. It responds to events, or triggers, by posting a new goal for Rascal to achieve. Finally, Alfred, the end user interface, allows people to program the Room by telling it the name of a new goal, demonstrating triggers and plans for achieving that goal, and informing the system of the conditions under which they would prefer one plan over another (i.e. the user records response “macros”). The entire communication is done by simple verbal commands or other natural forms of interaction (Gajos et al. 2002).

In this case, the authors explicitly claim that a system properly structured for self-adaptivity and reactivity to the environment, such as the Intelligent Room Project, provides an appropriate framework for end user empowerment.

It must be noted that the Alfred system records macros for outputs (goals and behaviours), not as much for inputs, so the system is not robust in recognizing contexts. Instead, the system understands simple triggers, but it presents a sophisticated solution for handling different possible responses in relation to each goals in its plate and to other user-specified goals. Thus, despite its complexity, the Intelligent Room Project is still a rule-based system. Simpler rule-based EUD systems exist and are becoming increasingly common, such as the IFTTT (If This Than That) mobile application, a widely popular free app that allow users to easily create conditional rules among other apps and smart appliances.
Adopting another approach, the project named *a CAPpella* develops a machine learning strategy to identify contexts (Dey et al. 2004). In order to ensure a satisfactory context-aware application, the authors focus on an end user development strategy of programming by demonstration. In *a CAPpella*, the users access an on-screen interface for indicating to the system the time-frames and the relevant recorded data of a contextual event, so the system knows what to look for when identifying contexts.

In their research paper, Dey et al. (2004) present the process of training the system to distinguish when a group of people or an individual in a room is having a meeting from when they are not. The system required exposure to a number of events (min. 5), followed by an end-user indicating the event, before it could distinguish a meeting from a non-meeting with a satisfactory percentage of errors (as low as 6.7% for 1-person meeting and 20% for 2-persons meeting).

A rule-based application would not be able to identify complex events in context the way *a CAPpella* does. Without machine learning, a system would require very specific, well-defined triggers to understand an event. In case of a meeting, perhaps someone would have to ask the system to set “meeting mode”, or else every time a group of people were present in certain rooms, “meeting mode” would be activated, even if the group did not intend a meeting.

The problem with *a CAPpella* system, however, has already been explored when mentioning the issues with inference engines. The training period required for a context to be identified can be cumbersome and frustrating, especially if new activities and contexts arise often. Additionally, errors in identifying context become more significant when considering the use of such applications in people's daily routine.

All the examples of EUD systems in smart homes and similar context-aware applications are concerned with the adaptive settings of home appliances and services (e.g. when to turn on the lights, when to start the coffee machine). In interactive architecture, authors are typically more interested in the adaptation of entire buildings' morphology (or specific layers of it), making previous research not immediately translatable to the problem of IA. However, the debates being conducted in those fields are the ones that more closely approximate, pragmatically, the problem of user empowerment in IA.

Addressing end-user development is only one dimension of the user control problem as it is approached in AmI and UbiComp. Especially if the system is expected to exhibit autonomous
behaviour, thus not being completely dependent on user input, strategies must be in place to allow the user an appropriate level of agency over their environment.

Bellotti and Edwards (2001) argue that the more we try to get systems to act on our behalf, the more we have to watch every move they make. The authors developed a few design principles that stirred great attention and repercussion in AmI. Apart from control, intelligibility is a central issue of their discourse. An intelligible context-aware system is a system that is able to represent to its users what it knows, how it knows what it knows, and what it is doing about what it knows (Bellotti & Edwards 2001).

Vermeulen et al. (2013) explains that many systems around us provide subtle intelligibility and control. Recommender systems such as Netflix, Amazon, App Store, or Youtube, which work by providing recommendations of related content to their users, are an example. In some of them, users can ask the system why a certain item was recommended to them and give feedback on that behaviour (Vermeulen et al. 2013).

Several studies exist in exploring ways to improve intelligibility and control. Vermeulen et al. (2013) introduce a design space consisting of six dimensions that play a role when developing interfaces for intelligibility and control:

- **Timing**: Intelligibility and control can be supported at different times during the interaction: before, during and after events take place.

- **Generality**: User interfaces and interaction techniques for intelligibility and control can be general or domain-specific (e.g., techniques for visualising location errors in navigation systems).

- **Degree of co-location**: Support for intelligibility or control might be embedded or integrated with the rest of the user interface versus external, when users are required to switch to a separate interface.

- **Initiative**: Users may need to explicitly request intelligibility information or invoke control techniques manually (user), or might automatically be presented with these features when necessary (system).

- **Modality**: Several modalities can be used to help users to understand or control the system (e.g. visual, auditory, haptic).
**Level of control:** The level of control end-users can exert over the system varies from intelligibility, where no additional control is added beyond intelligibility, over counteract, where users can perform the opposite action (e.g., undo), to configuration, where users can tweak predefined system parameters, and programmability where users can themselves (re-)define how the system works.

The aspects discussed in this section will be yet further explored with regard to interaction design when pertinent, in chapter 5.

4.5 Inhabitant agency in contemporary interactive architecture

It has been already argued that there is little recent research in IA exploring the problem of inhabitant agency. This section will review some of the works that I believe contribute to an understanding of the topic.

Cetkovic (2012) is one of the few authors to attempt to re-open the debate of user empowerment in IA, especially regarding the new breadth of freedom and possibilities that IA is expected to foster. As he puts it: “one would think that the greatest asset of interactive architecture is that it provides more options and freedom for the user. Instead, in reality users receive totally controlled spaces and movements – a misinterpretation of the term flexibility”. He believes the problem arises from the architects' perception of the user and of the user's role in the spaces.

Cetkovic (2012) believes that by focusing the interaction and communication strategies of IA on the concept of affordances, architects could avoid the risks of deterministic design. This would be so because, as Norman (1988) explains, the perception of any possible actions afforded by an object is mediated by the actor's own goals, plans, values, beliefs and past experiences. The expectation that this understanding would result in open systems and non-deterministic design, however, is very questionable, as the author himself implicitly admits.

Jeng (2012) also tries to define IA in relation to empowerment, by presenting the extension of human capabilities as one of IA's main objective; and the idea of inhabitant agency, as it has been discussed throughout this manuscript, seem to permeate Takeuchi’s (2012) description of his conception of IA. He refers to the term “Synthetic Spaces”, which he claims to exhibit the following two traits: 1) an
awareness of the power of physical architecture to influence human behaviors and psychology, and
2) an intent to let users neutralize, or take control of, that power of architecture.

A few other recent authors have come to address the role of the user in control systems in IA, but
without a noticeable interest in empowerment. Again, they use pragmatic arguments for increasing
inhabitants' control. Compared to what has been produced in AmI regarding user control and
programming, these debates in IA are clearly behind in maturity. However, being native to the field of
IA, these authors address layers of the environment which are not considered in neighbouring fields.

Sterk (2005, 2006a) is one of the few authors to discuss in detail how user input influences the overall
behaviour of the architectural system. He proposes a simple model which is comprised of user input,
spaces (the serviced spaces that we occupy), and structures (the external shells that shelter us).
Together, spaces and structures form the resulting architecture. The task of the control framework
Sterk (2005) describes is to “coordinate the activities of each building element to achieve a state that
reflects user needs”. The figure below illustrates his framework (Figure 10).

Figure 10 - Hybridized control model for responsive architecture. Source: Sterk (2005). Used with permission.
The system control is conceived as a hybridized model that allows separate reasoning processes of a reactive (or low-level) and deliberative (or high-level intelligence) nature to coexist. User input functions in the higher level, despite the fact that the user only interacts with the system in the lower level. Sterk (2006a) explains that “one may conceive of users’ interactions as being corrective”. For example, a user may adjust the behaviour of a thermostat to meet perceived changes in comfort. “Corrective actions are instances of direct manipulation that help simpler, automated systems perform well” (Sterk 2006a).

Another part of the “user input” component in Sterk's framework is the User-Model. The User-Model uses inference engines to provide responsiveness. It uses environmental data as well as data captured by watching an occupant interact with a space (including his/hers corrective actions), thus generating a contextual model that is capable of contextual responses (Sterk 2006a). How well the inference engine would provide context sensitive responses in an architectural setting is not discussed, given the fact that Sterk's framework is theoretical.

In Sterk's framework, it must be noted that the user is not allowed to interfere with the system with regard to its high-level decision making. Thus, in Vermeulen's et al. (2013) six dimensions of design space, Sterk's model presents a low level of control (“counteract”) and a user-sided initiative towards control. It is also apparent that in Sterk's framework, the responsive environment is designed with preconceived “logical” responses to a group of conditions, with limited support for expansion apart from the system's own learning capabilities.

Apart from the issue of the user, it is also interesting to note the way Sterk's system handles the interaction between structures and spaces. The system first attempts to solve a problem locally, using lower level responses. If that is not possible, an exception is issued to be handled by the centralized, higher-level control. The central control then handles the exception by issuing a request to another lower-level system. This form of internal flow can be extended to articulate the behaviour of a community of buildings (Figure 11).
Although Sterk does not mention Habraken or the concept of environmental levels, his model seems to suggest that solutions are first to be sought locally in the lowest environmental levels. When these cannot provide appropriate answers, a centralized control system request the engagement of higher environmental levels, in a hierarchical sequence.

As will be later discussed, however, this degree of detail in which Sterk discusses the behaviour of the system and the forms of user input is incredibly rare in IA. One reason may lie on the long gap of disinterest in user agency in the field. Another, perhaps most important reason, lies on the lack of built examples of truly interactive architecture.

For the last couple of decades, the most common form of addressing users as participating agents in the creation of their environment, both in IA discourse and projects, refers to the use of a person's behaviour as a seed in emergent aesthetic expressions. This view is well articulated by Wlaszyn (2011). She argues that “[i]nteractivity offers an explicit engagement for the user allowing anyone who interacts to become at minimum a collaborator and in some cases a co-creator of sensitive experience”. She goes on to question, with a phenomenological view of the world, if the explorations of non-linear interactive process are not just a derivation of aesthetic experience explorations.

This kind of approach has considerable resonance with interactive arts. As I state in a previous research (Costa Maia & Meyboom 2015), it is also much easier to address the potentialities raised by Wlaszyn (2011) with current inexpensive technology than to solve, for instance, the problem of architectural self-adaptation to unanticipated use demands. As a result, IA literature is populated with
interactive arts examples and settings of relative small scale. However, these projects are valuable to our discussion because they address user participation and collaboration in a fashion that has not been typically discussed in architectural projects. Some of those projects are illustrated in the figure below (Figure 12).

**D-Tower**
by NOX/Lars Spuybroek (2004)

Public art piece that changes color according to the moods declared by users in an online website. The data is aggregated daily.

Retrieved from: http://www.nox-art-architecture.com/

Image used with permission from author.

**Marling**
by Haque (2012)

Mass-participation interactive urban spectacle, animated by the voices of the public. The voices are given form through 3D light and color effects.

Retrieved from: http://www.haque.co.uk/

Image used with permission from author.

**Skies Painted with Unnumbered Sparks**
by Janet Echelman in collaboration with Aaron Koblin (2014)

Massive public art piece where vivid beams of light were projected as the result of small movements on spectators’ phones.


Image used with permission from author.

*Figure 12 - Examples of interactive spatial projects addressing user participation.*
As already argued, despite the fact that the figure of the inhabitant is very central to the discourse of IA, the matter of inhabitant empowerment itself has been only addressed marginally for the past decades. Furthermore, the lack of any framework or solid theoretical basis for the discussion of empowerment is also patent. However, this can hardly be considered a problem only related to the discussion of inhabitant agency and empowerment. Most of the field of IA lacks robust theoretical frameworks to structure its development.

An even more concerning difficulty relates to the very rare and very limited examples of built IA instances. The fact that Sterk’s (2005) interaction model is one of few that explain interaction and system behaviour to a minimally elucidative level of detail exemplifies the problem. For the most of the available discussion, IA only exists as a conceptual topic, which also renders it excessively vague despite best efforts.

An IA system must be defined still to viable details, beyond what is typically available in IA literature, before any judgement can be made concerning its suitability as a response to human agency. As it has been stated, it is one of the objectives of this thesis to conceptualize, design and develop a true IA system in order to enable further explorations on inhabitant agency in interactive spaces. The first step in the definition of an IA concept, however, is to understand the specificities of how such a system may behave and interact with inhabitants.

The next chapter will review main concepts in interaction design literature, consolidate important interaction concepts for the discussion of inhabitant agency, and refine interaction models that can be employed to represent the typical concepts of IA as depicted in IA literature.
5. A matter of interaction

5.1 Building around interaction

Interactivity is one of the key concept that presupposes the connection between IA and empowerment. It is also the concept that makes IA differ from conventional architecture fundamentally. It is therefore natural that an investigation of inhabitant empowerment in IA should focus primary on aspects of inhabitant-environment interaction.

In other words, rather than trying to understand the connection between different spatial forms and agency, it makes more sense to focus on exploring the connection between inhabitant agency and different aspects of interaction and behaviour.

Historically, discussions around the problem of interaction from early theoretical work in IA were highly connected to the theories of cybernetics and communication: interactivity is a conversation. Since then, the scope of the field has evolved dispersedly and different approaches have emerged. For instance, sustainability and environmental responsiveness started getting great attention since the 1990's (Fox & Kemp 2009), retaining prevalence to this day (Costa Maia & Meyboom 2015). These areas showed little concern for the problem of IA interaction with inhabitants, treating environmental responsiveness as a matter of objective performance.

A few authors, however, still investigate IA from a communication theory perspective (e.g. Rizopoulos & Charitos 2011), and the idea of interaction as a conversation marks the very definition of the field in several of the studies I have reviewed (e.g. Jaskiewicz 2008). The reader may refer back to chapter 2 for a revisit of these concepts.

In the current chapter, I intend to scrutinize not only further levels of understanding of interactivity, but also pragmatic levels that can directly inform the design of IA systems. The objective is to define, characterize and explore in terms of agency basic interaction models for IA. For that, I start by presenting a non-exhaustive and commented review of relevant ideas from fields entirely devoted to the study of interactivity between people and technological systems, such as Interaction Design and Human-Computer Interaction (HCI). Then I use those insights to carry out the exploration of the interaction models in IA.
Based on the current interaction approaches to be found in IA literature, I will propose basic interaction models to be explored in IA, accompanied by a discussion on how certain strategies can be used to foster empowerment.

5.2 Interaction design background and other considerations

5.2.1 IA and interaction design

Several papers in IA have drawn upon research in HCI and Interaction Design (e.g. Jeng 2012). Remarkably, IA authors build more often upon HCI research than upon IA's own contributions (Costa Maia & Meyboom 2015). However, the models they reproduce do little to bridge the gap between what is done in HCI and the particularities of IA, especially when considering the problem of empowerment. For this reason, this chapter will review concepts from those fields directly and develop them in the context of inhabitant agency.

5.2.2 Goal-oriented frameworks

In the literature, a countless number of studies can be found to propose models or frameworks for interaction involving complex system (e.g. Card et al. 1983, Frohlich 1992, Schomaker 1995).

Among these, a few prominent models stand out to my attention for explicitly incorporating the idea of user's goals as a central component. As it has been already said, the notions of empowerment or agency refer exactly to the capability of people to act in pursue of their own goals. Thus, interaction models that are built around the intention of facilitating people's achievement of their goals are of particular value to this research.

Among the models surveyed, the popular “layered model” proposed by Donald Norman (1986) in his Theory of Action may provide the best reference for the present research. Norman's approach is also closer to key concepts of some general theories of communication, e.g. the Layered Protocol theory (Waugh & Taylor 1995), and to the cybernetics view that form the basis of IA.

The layered model describes seven different layers of user action. On the top layer, the user formulates a goal. The next three layers describe the stages for the execution of the goal: planning, action specification
and *action execution*. Finally, the three bottom layers describe the feedback of the action executed: *perception, interpretation* and *valuation* of the system's state.

The input and output flows of information are clearly marked in the model. Norman (1986) understands that during the interaction process, users need to bridge the Gulf of Execution (input: *planning, action specification* and *action execution*) and the Gulf of Evaluation (output: *perception, interpretation* and *valuation*).

The basis of such model is the argument that people think in terms of goals and intentions, which are psychological variables. However, as Norman (1986) argues, “the task is to be performed on a physical system, with physical mechanisms to be manipulated, resulting in changes to the physical variables and system state”. Thus, between the goal, a psychological variable, and the physical actions required upon the given mechanism there is a large gap, resulting from the discrepancy between psychological and physical variables. Likewise, the system's display of its state must be interpreted in terms of the original goal, creating a new, asymmetric gap. The following image presents a diagram of the model (Figure 13).

*Figure 13 - Layered model by Norman (1986). Adapted by the author.*

Norman (1986) acknowledged that this is a simplified model of the real-world problem. In reality, some stages of the layered model might be skipped or repeated. Goals might be changed or generate
child-goals. In some situations, the user is even reactive to events, as opposed to starting an interaction with defined goals and intentions. The simplification is, however, helpful in understanding the overall process. It also helps on speculating the specificities to be encountered when addressing IA systems.

The illustration below presents an initial, basic diagram of the model applied to a IA system that only performs for output physical adaptations and that is essentially responsive rather than (human-like) intelligent, a common conceptual setting for IA projects\(^27\) (Figure 14). This model application is presented here for exemplification of how the layered model can help investigate empowerment processes in IA.

\[\text{Figure 14 - Layered model adapted to basic IA system.}\]

\(^{27}\) The models represents the type of IA interaction defined by the second group of IA authors presented in the last sections 5.3 and 5.4.
The diagram represents a model in which goals define a situation of inhabitant agency towards architecture. That is, in such case, the goals refer directly to the architectural object.

One specificity of the diagram above refers to the fact that no output translation is required, given the IA system changes itself and the physical transformed system is the output in its most accessible format already. Another specificity refer to a narrower Gulf of Evaluation that result from the lack of necessity of mapping output formats. While in conventional desktop computers a common strategy to reduce the Gulf of Evaluation it to create an illusion that the user is working directly in the problem domain, in IA the problem domain is the real world, immediately apprehensible.

Additional – complementary or intermediate – forms of output are possible in more complex systems and will be discussed briefly. Concerns with modes of input, however, will be present in all situations, even if the input is not deliberate.

Bongers and van der Veer (2007) explore the different ways in which input and output messages can be considered in IA. These authors review HCI literature and propose a multimodal framework for interactive systems, including IA, where the interaction space occurs closer to the human space than the machine space. A modality, as they explain, refer to a communication channel, and the combination of multiple modalities are commonly explored to achieve a higher bandwidth of interaction.

Bongers and van der Veer (2007) summarize the following dimensions of a multimodal interaction space:

• Levels: (physical), syntactic, semantic, (task), (goal);

• Modes: symbolic, iconic, para-linguistic, involuntary, subconscious, continuous;

• Senses/modalities: seeing, hearing, touching.

The authors claim that any interaction style can be placed in this space. An interaction style is, however, “not a place in the Interaction Space but a trajectory through it, particularly described in the levels (getting from the goal to the action, and back again analyzing the results of the action)” (Bongers & van der Veer 2007). The authors describe a process particularly similar to the layered model by Norman (1986). However, they focus on the levels, modes and senses associated with the stages of the interaction process.
Despite the importance of understanding the different modalities of communication in an interactive process, I believe the current research will benefit further from a discussion of general models and strategies than of specific modalities. In this case, it might be more useful to classify IA systems with regard to the strategies behind the use of different modalities than with regard to the specific selection of channels. For instance: Does IA responds to inhabitants only through changes in its physical state? Does IA use different modalities as part of its mode of response? Does IA use different modalities as intermediary steps before physical response, such as to ask if the user agrees with a certain behaviour? These different strategies would have an impact on how the interaction model is arranged.

Another important concept present in the two previous figures and that have not been discussed yet is that of mental models. Mental models figure as a background pane for some of the mental activities during interaction, influencing their framing. The next section discuss this concept in further detail.

5.2.3 Mental models

Mental model is a central concept to the field of HCI. Upon exposure to a system, users can develop a mental model of that system; that is, a conceptual understanding of what the system is and how it works. As Norman (1986) puts it:

> I believe that people form internal, mental models of themselves and of the things and people with whom they interact. These models provide predictive and explanatory power for understanding the interaction. Mental models evolve naturally through interaction with the world and with the particular system under consideration [...]. These models are highly affected by the nature of the interaction, coupled with the person's prior knowledge and understanding. The models are neither complete nor accurate [...], but nonetheless they function to guide much human behavior.

Mental models are also important concepts in early discussions around IA (e.g. Negroponte 1975, Wellesley-Miller 1975), as they are very relevant to the artificial intelligence debates of the time. When addressing IA as an intelligent participant in a conversation that manifests understanding, the user will have not only a mental model of the building, but also a mental model of himself, and a mental model of the building's model of himself. All of these are important factors influencing the interaction.
Blackwell (2006) explains that the description of the mental model as a user’s internal data representation was derived from several research streams in the 1970s and 1980s. It encapsulates knowledge from psychological and anthropological traditions in one “objective, formalizable, and symbolic entity” to be used by engineers, who are not familiar with mind-related sciences.

The idea of using computational descriptions of the user’s mind in design popularized in the late 1970s, followed by a discourse of empowerment. It was said that users would be beneficiaries of the user model, through which the privileges of programmers and scientists would be extended to others by via of making computational abstractions more accessible (Blackwell 2006). It was the beginning of the “desktop” metaphor, which is not by any means left uncriticised but which is thought to be part of the computer democratization revolution to have occurred in past decades.

Considerations of mental models in the context of IA raises some challenges. The first one is that people typically already have strong mental models of what buildings are and how they behave. Also, given the fact that the built environment is composed of different juxtaposed layers, which extend themselves in a continual fabric, it might be difficult for users to build unified mental models for IA – or for an ecosystem of IAs. Scholtz and Consolvo (2004) point out a similar question regarding Ubiquitous Computing. They ask: “how do users know when they are in a smart room, and how will they know how to interact with such a room?”. In fact, IA can easily go from empowering to oppressive if inhabitants of the space cannot understand the system.

Given these difficulties, I believe that metaphors provide a useful way to study different forms of IA interaction, especially with regard to empowerment. The issue of metaphors is directly related to that of mental models. Metaphors are intended to encapsulate an understanding of how a system is expected to work a priori, as part of a deliberate design effort. That is, they seek to start with the desired mental model users should formulate, one that is familiar and pertinent to the problem domain, allowing designers to conceptualize a system design based on that information, not the other way around.
5.2.4 Metaphors for empowerment

In this section, I do not aim to cover the UI design strategies commonly found in HCI textbooks when addressing metaphors (Blackwell 2006). I propose, instead, to discuss typical metaphors and their relation to user empowerment, as this debate is one already open for exploration.

With regard to computer interfaces, Weller and Hartson (1993) argue that direct manipulation interfaces, through metaphors such as tool and model world, provide the most empowering environment for users. For the authors, empowerment is about one's confidence in personal knowledge and in the ability to take actions based on that personal knowledge.

Weller and Hartson (1993) founded their arguments for direct manipulation metaphors in the cybernetic idea of feedback as central to the operation of human systems and their interactions with machines. From this perspective, closed-loop styles of human-computer interaction speeds a person’s learning of the system through trial-and-error exploration, thus expanding knowledge and confidence. “Rather than just being a tool that extends human capabilities”, they argue, “the computer in an empowering environment is part of a control loop that includes the human user”.

The tool metaphor is characterized by a number of aspects, one of them being transparency. Weller and Hartson (1993) uses Heidegger’s example of a hammer for analogy: “[t]o the person who is hammering, the hammer as such does not exist”. During use, the hammer is taken for granted without explicit recognition of it as an object, only arising to the foreground in the event of a breakdown. The authors explain what this concept mean for interaction design:

In a proper direct manipulation interface the domains in which actions are generated and interpreted are designed so that the user is not called upon to deal with complexities that belong to other, less appropriate domains. The interface designer has created the language, indeed the world, in which the user operates so that it is not a jumble of domains. This world has ontological simplicity, making the network of tools seem ready-at-hand, rather than presenting situations of nonobviousness [...].

28 The empowering environment “utilizes the computer’s strengths in structured symbol manipulation to empower human accomplishment through a division of labor: the machine handles the routine mechanics of a task while the person is immersed in its higher-order meanings” (Dede 1987 apud Weller & Hartson 1993)
This ontological simplicity, however, carries with it constraints and biases that have already been discussed in section 4.2 of this document.

Another metaphor related to direct manipulation is the model world metaphor. It consists of giving users the illusion of acting upon the objects of the task domain directly. The real or virtual problems are presented in the domains that users conceive them; and the interaction is designed so that user can assume the computational representations are the things they refer to (Weller & Hartson 1993).

The tool and model world metaphors are in fact the basis of current direct manipulation paradigms of human-computer interaction. But how are they pertinent to IA? The model world metaphor is of clear relevance to the discussion of inhabitant agency in architecture: as already suggested, in IA the object of manipulation is the architecture – or the world – itself. In situations of complex behaviours and communication channels, however, extra representation layers may still be constructed on top of the real world. Given the appropriate model world metaphor of this additional layer, inhabitants may continue to perceive their actions as having direct effect on the world.

The tool metaphor might be particularly relevant in situations where the inhabitant goal is external to the architecture or the built environment, and instead requires the use of architectural spaces for support in achieving said external goals. We can conceive a hypothetical situation where the system setup allows for the perception of IA as being a tool of its own making, thus being both the tool and the world. This could create ambiguous forms of realization, but existing examples were not found for examination.

Another relevant metaphor for the discussion of IA is that of human-human interaction. As it will be discussed in section 5.3, a considerable number of authors in the field of IA conceive the problem of interaction as one of conversation with a human-like intelligent building.

The human-human interaction metaphor takes the form of “conversations for action”. Weller and Hartson (1993) explain that these conversations entail an interplay of requests and commitments that are directed toward explicit cooperative action. Domains of conversation are established where common pre-understandings allow for communication with a minimum of words and conscious effort. Similarly to the tool metaphor, persons only become explicitly aware of the structure of conversation when a breakdown calls for corrective action (Weller & Hartson 1993).
Waugh and Taylor (1995), however, argue that independent participants in a conversation hold different values and goals, even if similar, and that at some point these goals can be conflicting. According to the Layered Protocol theory, the authors specify three “independences” in a human-human interaction metaphor: independence of design, independence of sensing mechanism and independence of action. They explain these concepts in the following terms:

Independence of design means that the processes for generating and interpreting communication are not identical in both partners; independence of sensing mechanism means that neither partner can be certain of what the other is actually sensing; independence of action means that neither partner is certain as to all of what the other partner is doing at any given moment. Given these conditions, neither partner can guarantee the reception of a particular message by the other, regardless of the amount of redundancy used to encode it. (Waugh and Taylor, 1995)

Waugh and Taylor (1995) warns that, because two intelligent entities cannot resort to redundancy to ensure a message was decoded without errors (the way machines do), they must resort to the notion of feedback. Feedback is used to indicate if a message was received correctly or if some problem exists. This has been repeatedly discussed in the context of intelligence and IA.

Weller and Hartson (1993) observes that interactive systems “built upon the conversation metaphor enable the user to gain the ‘power in the abstractions that language provides’”, however this sort of interface denies to the user direct engagement with the objects of his/her interest.

The lack of direct engagement might be prejudicial to the perception of inhabitant agency in architecture, when compared to a direct manipulation condition; however, this drawback might be compensated by effective communication and performance of the system.

Many other models, interfaces and metaphors of interaction could be discussed. However, their sources are fragmented, and little further has been found regarding possible connections between metaphors and empowerment. The last concept I address extensively in this review of relevant HCI literature is that of embodiment. This concept can be studied complementary to the metaphors already discussed.
5.2.5 Embodiment

Fishkin (2004) provides a classification of both embodiment and metaphors in relation to Tangible User Interfaces (TUI). Although his categories of metaphors do not contribute much to the discussion of IA, he presents an interesting scale of embodiment that could be used in the context of IA, after adaptation.

His understanding of embodiment refers to how closely tied is the input focus to the output focus in an interaction: “To what extent does the user think of the states of the system as being ‘inside’ the object they are manipulating? To what extent does the user think of the state of computation as being embodied within a particular physical housing?” (Fishkin 2004).

I believe that embodiment is a critical dimension of IA. Different impressions of a system may foster very different attitudes towards the architecture, as well as very different perceptions of empowerment. The importance of this dimension of IA is expected to become clear as I discuss the four levels of embodiment I propose for the field.

Despite being based on the work by Fishkin (2004), the classification I propose diverges significantly. After trying to apply his classification unmodified, it became clear that IA required something better tailored to its particularities. The four levels of embodiment I propose are described as follows.

*Full:* the state of the object is fully embodied in the object. That is, inhabitants engage with an architectural entity and see the effects of their actions on the very same entity. Thus, inhabitants perceive themselves as interacting directly with the building, which changes its own state in response to the inhabitants.

*Coupled:* the output is tightly coupled to the focus of the input. Inhabitants must use tools or coupled interfaces of a different domain to influence the architecture. For instance, inhabitants may use a tablet device to communicate with the building. Inhabitants still perceive the building as an interactive entity that changes its own state according to the interaction, but the interaction itself must be conducted through an interface that translates the inputs.

*Disconnected:* the interactive entity is disembodied from the architecture, although a link persists between them. It is useful to think of the fictional examples of “HAL 9000” from 2001: A Space Odyssey (1968), or “computer” from the StarTrek series. The entity with whom the inhabitant
interacts is no longer perceived as the building itself (or the ship, in the examples given). The building is an inanimate, although actuated, object. The interactive system is rather perceived as a component of the building, which in turn has the power to affect change to the whole building. Thus the inhabitant affect changes to the building indirectly, through the interactive entity.

*Detached:* the interactive entity is disembodied from any architecture and may establish links with different architectural elements or layers when desirable. A speculative example would be the case in which personal mobile assistants, such as Apple's Siri or Microsoft's Cortana, could connect to a flexible room or building and act as the brain, or one of the brains, of that interactive architecture setting.

Fishkin (2004) argues that as embodiment increases, the “cognitive distance” between the input mechanism and the result of that mechanism decreases. Thus, full embodiment would have great potential for inhabitant engagement and directness of action, which Weller and Hartson (1993) indicate as important determinants of empowering interfaces. This setting also provides supports for interaction to happen seamlessly during activities, functioning as a “calm” system. Full embodiment, however, may limit the ways that interaction can occur, especially regarding the input of more complex messages.

Coupled embodiment, on the other hand, could expand what is possible to achieve. Interaction through auxiliary interfaces would allow for the end-user programming of complex behaviours, for example. The need of an intermediary tool, however, would require that the user have both access to the intermediate interface and sufficient motivation to access it; thus if the tool is not omnipresent, the interaction only supported by the tool would require the inhabitant to actively reach for it, potentially disengaging from the activity of interest.

The disconnected and detached embodiments are not pertinent to any discussion of IA that I have ever come across. We may question if such examples could qualify as IA at all. They seem to escape what is typically understood as IA in the field, yet they are a natural evolution of the embodiment levels, as well as reasonably possible settings.

Finally, it must be said that levels of embodiment can be studied from different perspectives and with different outcomes. For instance, Fels (2004) defines four types of relationships between person and instrument that can be categorized depending upon how deeply embodied an object is into a person
or how deeply embodied a person is into an object. The relationships established is depended on the person's perception. These perceptions are: 1) the object is external to herself and responds to control; 2) the object is embodied within herself, i.e., an extension of herself; 3) the object is external to herself and does not respond to control; and 4) herself is an extension of the object.

The categorization proposed by Fels (2004) talks about interfaces for musical instruments, proposing an alternative way to look at HCI and design for expression and pleasure. They could not be immediately applicable to IA, if IA is not discussed in those terms. However, Fels’ approach to interaction with regard to the aesthetics of the forming relationship results in interesting observations. So far, the concepts considered in this thesis were crosscutting and did not explore the longer-term development of a relationship between interactive system and user.

It is worth questioning if inhabitants could feel embodied by an IA system they are a part of, as opposed to being an autonomous subject who actively engages with the system in a two party interaction. It is also interesting to speculate on the forms of empowerment that would emerge from these situations. It is possible, for instance, that feelings of awe in architecture would contribute to a person's perception of being embodied in the system. It is also possible that complex perceptions of belonging, resignation and power would develop.

This approach to the study of embodiment is, however, fundamentally different to the approach adopted in the present research, and is not considered complementary to it. The classification I propose ranges from the interactive ethos being completely embodied in the architecture to being completely disembodied. Fels' (2004) classification, on the other hand, does not refer to the locus of the interactive ethos. It refers to relations of control between subject and object, which are also of importance.

In the next section, I discuss more variables that I believe to be important components of the inhabitant empowerment framework, but that unfortunately have little supporting literature.
5.2.6 Other variables: more aspects of relevance for understanding IA interaction

Apart from the main concepts already approached in this chapter, related concepts exist that can be productively incorporated into this discussion. I will explore a few which I believe to be relevant to how IA systems are perceived by inhabitants. The first of these is the concept of integration.

Several authors in the field of IA have criticized existing automated systems as being add-on systems (e.g. Jaskiewicz 2013), that is, they are not perceived as part of the whole architecture, but as an isolated element. Examples of such is the elevator system. Even when the elevators demonstrate some level of intelligent behaviour, they tend to be perceived as an isolated system rather than an IA component. Similarly, a network of smart appliances and components, typical to smart homes settings, may not be perceived as an integral part of interactive architecture, but simply as an add-on system in a static and conventional architectural environment.

On the other hand, projects where the building enclosure is the only element of responsive nature, for instance, figure in IA publications as examples of interactive buildings. Examples abound, such as the famous Institut du Monde Arabe, by Jean Nouvel. In these cases, the enclosure is perceived as an integrated part of the architecture, and not as an add-on system.

Note that add-on systems may present full embodiment, yet this full embodiment does not refer to the architecture, but to the isolated system only. For example, a smart elevator might present full embodiment, being perceived as the integral entity that encompasses the system’s ethos, yet also being perceived as something independent from the broader building, not integrated. Where integration is complete, full embodiment might be perceived as pertaining the entire building or space.

I believe that levels of integration can only be solved during the design stage, through an effort of conceiving interactivity comprehensively. However, empirical tests are still required to identify the main determinants of such integration, given it is a rather subjective problem. Additionally, I have not found any formal study of the problem of integration in IA.

Scale of interaction is another related concept that could be explored. The steering wheel of a vehicle, for instance, is a representation of a larger effect, i.e. the entire vehicle’s direction. Sometimes the interaction in architectural settings may happen at a one to one scale. It is also possible that the input in IA is of small, localized dimension, yet the resulting effect is of the entire building’s scale. Scale of
interaction may be a complementary notion to the levels of embodiment, but little is found in the literature about it. Nonetheless, I expect scale of interaction to have some influence in inhabitants' perception of empowerment. I would speculate that the larger the scale of the response, the greater might be the perception of empowerment.

Another crucial set of variables, however, refers to something that has not been discussed so far: the inhabitant him/herself. As has already been suggested in chapter three, particular characteristics of individuals, such as locus of control, have an influence on how people perceive agency. In this section, I will address individual fluid preferences that are situational and related to specific interaction events, as opposed to constant personality traits.

The first one is about situational preferences for engagement or disengagement. IA is not only a system, but it is also the environment in which people conduct all of their daily activities. It is always present.

In Metadesign, the same user will assume different and non-concomitant roles during the use and development stages of a system, depending on the situation at hand. These roles change back and forth between “passive user”, “power user”, “domain designer”, etc, even if the user is an expert developer (Fischer & Giaccardi 2006).

In IA, it is possible that an inhabitant is at same time designer and user of the same system. However, situations will appear in which inhabitants will prefer to be only users or only designers. People might also want at times their environment to just be static and unresponsive, non-interactive. Thus, people's perception of IA will depend on whether they want or not to be engaged with, or to be engaged by, IA in a given situation, for a number of personal reasons, regardless of their primary goals or how IA could assist in these goals.

Inhabitant's situational preferences for level of control must also be taken into account. Sometimes, inhabitants might wish they have full control of their environments, analogously to driving a sports car. At other times, inhabitants might prefer to let go of control and focus on other things, analogously to being a passenger in a limousine.

Different authors would argue inflexibly for different levels of control. Heinich and Eidner (2009), for instance, present a critique against the “limousine” form of treatment:
It almost seems as if the developers of the “intelligent houses” presuppose a passive inhabitant, who wants to be disburdened of as many tasks as possible, to be looked after, guarded, and entertained. Architecture offers here the wrapping for application programmed and predetermined by specialists.

On the other hand, a few authors make an argument against the “sports car” form of treatment. Cetkovic (2012) denounces the problem of giving people full control of everything, putting inhabitants under cognitive demand and potentially limiting their interest in engaging with IA. Similarly to Marc Weiser and his advocacy for “calm technology”, Cetkovic (2012) warns that if all environments are to compete for the attention of the user, the consequence will be a dissonance and overload of signals and events - a scenario which the user would try to avoid or ignore altogether.

However, it is not possible to draw rules for situations where engagement or control would be desirable and for when they would not. It is not possible because these preferences can vary greatly with culture, values, age, mood, habits, affective attributions, among countless others. It is, therefore, important to consider inhabitants' empowerment towards the intended empowering system itself: ideally, they should be able to choose between different levels of control.

Other variables can also be mentioned here that have been already presented in previous chapters, such as strategy of context awareness design, intelligibility of system, and initiative of interaction.

It is expected that several more relevant concepts were left out of this review. Yet, I believe that the main determinants of how people may perceive and interact with IA systems have been established, and will be able to inform the description of interaction models of IA.

5.3 Introduction to the problem of interaction in IA

The purpose of this thesis is not to invent new or improved models of interaction for IA. Instead, I aim to delineate typical models of interaction already described in IA literature, operationalizing them to further detail, so that they can inform the development of archetypical instances of interactive spaces. Therefore, this section will formulate an introduction to the descriptions of IA interaction commonly found in the literature.
Overall, despite the many exceptions, the large majority of publications addressing IA seems to treat the whole interaction process as a black box. Again, the lack of built, fully functional IA buildings or spaces might be the culprit for the lack of specificity. With most projects being very simple reactive systems, or solely speculative altogether, interaction feels like a given and invariant issue.

In general, I observed that the descriptions and analysis of interaction that can be found in IA publications may be roughly classified in three groups. The groups are hardly isolated categories, but rather sequent marks in a continuum.

The first group of authors assume that IA will not only have human-like intelligence, as it will interact as such (e.g. Adi & Roberts 2010, 2011; Achten 2013). Interaction happens via natural speech as well as deictic and representational gestures, following the “put-that-there” paradigm, and possibly extending to cover the whole breadth of human communication forms.

Negroponte (1975) comes to suggest this kind of building may be like a new member of the family. Calderon (2009) discusses the social-political possibilities involved in IA’s active participation in society, as a citizen. In such cases, the problem of personal interaction becomes a problem of personal relationship: what kind of personality does my house have? Does it want to help me with my chores today? Was it flirting with my boyfriend? Am I keeping a sentient slave? Interaction in such conditions is easily deflected into the wider discussion of autonomous artificial intelligence, which far exceeds the scope of this research. I, however, personally believe that this sort of intelligence may be desirable in a number of entities and applications, including ones that may directly influence architecture, but the built environment itself is probably not one of these cases.

The second group of authors is by far the most numerous (e.g. Eastman 1972; Fox & Kemp 2009), although their understanding of IA seems to avoid the discussion of interaction in detail. They are the group that the black box critique most suitably fits. These authors describe systems that will intelligently learn all it needs to know by observation, requiring only corrective feedback when necessary. Yona Friedman would call such approaches paternalistic. Matters of human-like intelligence are not immediately relevant to this group, even if the system intends to mimic human-like learning. In these cases, IA is the perfect machine that can anticipate needs when these needs are reasonably

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29 For instance: “HAL 9000” from 2001- A Space Odyssey (1968), or “computer” from the StarTrek series.
predictable, provide logical spatial support to activities it understands, and allocate/manage spatial and functional resources in ways to better support specific goals. The machine is efficient and invisible.

The interaction black box precludes an in-depth analysis of different interaction strategies, because of what appears to be two underlying assumptions: 1) the machine is nearly flawless and can successfully learn and adapt to changing conditions without the need to bother inhabitants, and 2) the inhabitant wants to be disburdened of as many tasks and requests as possible, expecting IA to act as a calm technology. What happens when the inhabitant does want to take control or interact, however, is mostly overlooked.

The third group of authors, perhaps of smallest representation, describe the emergent behaviour of distributed intelligence and/or the organic-like constant adaptation of a building to the ecosystem it is inserted in (e.g. Pan & Jeng 2008). Interaction with inhabitants is undefined, possibly occurring in different ways, but above all it is non-deliberate. This kind of IA is perhaps the one that most closely approximate the natural environment around us. Explorations in this area, however, are too vague to establish a discussion about person-environment interaction modes.

Several publications in IA, of course, are expected to escape this simplified classification arrangement. However, after reviewing a significant number of publications in previous endeavours (Costa Maia & Meyboom 2015), it so appears that a majority of interaction descriptions and suggestions will be easily encompassed by the three groups described above. Nevertheless, it has also become evident to me that much more research is still needed in both the conceptual and the pragmatic issues of inhabitant-IA interaction.

For the purposes of my research, I will suggest a new group of interaction, on top of the ones presented so far from the literature. This new group does not have representatives in contemporary literature in IA (or, at least, they have not been found). Yet, the proposition to include this new group is pertinent when considering the debate of technological vehicles of participatory design and of empowering interfaces in computer sciences. The new group is presented in the next section, before all groups are consolidated in interaction models in section 5.5.
5.4 One more interaction for inhabitant agency

In his book from 1975, “Soft Architecture Machines”, Negroponte puts forward his notion of what a computer enhanced, responsive architecture should be. He shares with many other authors the idea of an architecture that can adapt itself to changing needs. “The general assumption”, he claims, “is that in most cases the architect is an unnecessary and cumbersome (and even detrimental) middleman between individual, constantly changing needs and the continuous incorporation of these needs into the built environment”. Thus, Negroponte (1975) explores the increasing removal of the architect and his design function from the design process, until the physical environment is conceived with “the ability to design itself, to be knowledgeable and to have an autogenic existence”.

Not every author, of course, endorses Negroponte's view of a completely autogenic environment. Most authors, however, do imbue IA with some degree of autogenic character in their discourse. The idea of a change of state is inherent to the common understanding of IA. This change of state may be predetermined, but most often it is said to be based on context and changing needs.

The concept of interaction seems to imply an indeterminacy (or at least avoid hard determinacy) of any IA outcome, in opposition to traditional architecture being a finite process, designed and built in a top-down, fully predetermined manner. However, if the architect is eliminated as an immediate translator of needs, culture, values, etc, something else must take its place in defining the parameters for a resulting design, or for a change of state. In the interest of fostering inhabitant agency, it can be easily argued that the inhabitant himself must be the one to set the new parameters.

This can be done (1) by allowing the user direct control, or (2) by definition of an emergent system that responds to the actions of the user, like a flock of birds whose behaviour responds to disturbances, or (3) through a learning by observation process. In either case, the design must be responsive to the user. These roughly relate to the options addressed in the literature, except for the one where the inhabitant is given full control. Interestingly enough, this option in not discussed. For this reason, and with an interest in inhabitant agency, this section will try to develop such option further.

If IA is to be designed as a learning system that can adapt to unforeseen conditions, the strategy that is most recurrently discussed in literature, this implies that the system possesses initial rules of what adequate spaces, supports and responses for any activity might be. Even if corrective input is allowed,
this may be still considered a highly deterministic approach. It also presents serious technical difficulties that have been discussed in the previous chapter, especially regarding current limitation of context-awareness in machines.

On the other end of the spectrum, allowing inhabitants direct control of the system can be overwhelming. As already mentioned, Cetkovic (2012) talks about the problem of information overload in a situation where every piece of technology competes for users’ attention. He recalls Mark Weiser’s warning on the need for “calm technology” and advocates for peripheral awareness as a main channel of interaction between IA and inhabitants.

However, if we are discussing inhabitant agency and empowerment, would not just giving people full control over the IA system be the immediate answer to the problem? Maybe in some cases and not others. For instance, some forms of empowerment may arise from behaviours that the user might not be able to exert full control over, or the constant need for control upon the means may hinder achievement of certain goals.

Furthermore, if a system is completely controllable, it is difficult to make a case that it can still be understood as IA. Not a single publication in the field describes such a system for IA, and it generally does not fulfil the most basic definition for the term. This system would rather be an adaptable architecture with automated functions (e.g. executing a command to move a movable wall, instead of pushing the wall yourself). IA, to be IA, must involve some levels of internal computation.

One solution to have a system proving great control extents to the user and still classify as IA may be based on the concept of dynamic stability. Sterk (2006a) explains:

> [...] dynamic stability [...] enables an automated system to outperform a person who is doing the same job, improving the systems overall performance or safety. For example by removing the need for a driver to concentrate upon controlling a car brake skillfully enough to prevent its wheels from skidding, drivers who have cars with anti-skid braking systems are left with a single very simple operation to perform – “braking.” As such feedback mechanisms can be used to encapsulate many complicated operations into a single, symbolic action (Sterk 2006a).

Having inhabitants focusing on symbolic actions, while leaving the system to provide the best outcomes under the inhabitant's terms might be a very adequate approach to inhabitant agency in IA.
In computing, Weller and Hartson (1993) define similar approaches as the most empowering ones. The empowering environment “utilizes the computer’s strengths in structured symbol manipulation to empower human accomplishment through a division of labor: the machine handles the routine mechanics of a task while the person is immersed in its higher-order meanings” (Dede 1987 apud Weller & Hartson 1993).

The distinction between control possibilities is explained by Weller and Hartson (1993) as genres of control loops. The second genre, they say, “informs the user immediately of state changes resulting from each small input action, but the computer system is not structured to help with the problem-solving process in the specific application domain”. This is a case where settings could hardly be considered IA. The third genre they discuss, however, is the one that they have been advocating as empowering: “the computer provides functionality to help in the problem-solving process”.

Such system is referred to as a hybridized model by Sterk (2006a), who claims it to be both self-regulatory and participatory. In IA literature, however, I have not found any description or project defining how such a system could be designed, or how it could behave, except for Negroponte (1975). The author believes that a human-like intelligent system is the only way for an adequate level of assistance in the problem-solving process to be effective.

I have not merged this kind of assisted control strategy group with the human-like intelligence group because it is not true that every author seeking one would also be seeking the other. Negroponte (1975) is perhaps the only author I have come across to make this bridge explicitly, that is, to suggest that human-like intelligence can be used to give inhabitants an effective form of extensive control that is, at same time, assisted and collaborated. Other authors, like Yona Friedman, describe assistive systems that provide inhabitants with feedback on the consequence of their design decisions, without the need for human-like character and interaction.

Friedman’s work is not here considered the primary example of this group of interaction because it is not specifically presented in the context of IA. More generally, descriptions from IA literature would fall in the general groups presented in the previous section.

In this section, I have exposed a few considerations on what could make an interesting system design for inhabitant agency in IA. It is more of a thought record than an extensive investigation of possibilities. The purpose of this research is not to devise, a priori, the best interaction strategies for
empowerment, nor to provide specific design guidelines. However, because the notion of empowerment seem so close to the notion of extensive control, I have chosen to define a fourth “type” of strategy to be investigated, alongside the three already discussed in the previous section.

I strongly believe that the means of interaction is one of the most determinant aspects of how any inhabitant will perceive their interactive environment and of how that environment empowers him or her towards his or her goals. It is not possible to discuss IA, or speculate on its social impacts, without specifically defining its models of interaction. For this reason, the next section will seek to consolidate four basic interaction models that will serve as the grounds for a less speculative investigation of inhabitant agency in IA. In the following chapters, the interaction models will be further developed, implemented and tested in a real world scenario, thus providing generalizable information on how IA, in its archetypical forms of interaction with inhabitants, may support the argument for inhabitant agency.

5.5 Consolidating interaction models of interactive architecture for inhabitant agency

In the previous two sections, four different groups of IA interaction descriptions were presented in the terms these descriptions are typically found in IA or broader literature. In this section, these descriptions will be encapsulated in defined models of interaction. Ultimately, I used these models to prototype and test the different archetypes of interaction with regard to inhabitant agency.

The four models are termed as follows: self-adjusting model, direct manipulation model, human-like intelligence model and emergent behaviour model.

The self-adjusting model refers to a self-adapting space that requires little deliberate inputs from inhabitants (most of corrective nature) and accepts only logical, machine-like arguments for self-improvement.

This model is intended to anticipate needs and assist inhabitants towards their goals, without requesting great involvement from users. In doing so, and assuming it provides the correct kind of assistance when needed, it takes away from the user the cognitive load of making certain choices and demands, concerning the interaction itself, and concerning all informational aspects of which a “calm
technology” can spare its users. Thus, by reducing cognitive load, this system maximizes overall performance of the necessary tasks to reach any goal.

Fox (2010), for instance, uses an example of how a movable cabinet can assist inhabitants in retrieving food items as desired. Upon the understanding that the inhabitant is preparing to cook, the self-adjusting setting would automatically make the cabinet's spice shelf within reach\(^{30}\), thus facilitating the completion of the task. Apart from the actual physical work that would be otherwise required to reach a high cabinet, the system also takes away from the user the need to plan for that action.

If the goal of the inhabitant refers to changing the house's behaviour extensively or to reconfigure the organization of the architectural spaces, however, the self-adjusting model would provide little support. It would also be of little help when facing new situations or ones it still does not understand. User input is a secondary aspect in this model, and agency towards architecture as a goal in itself is largely neglected.

The possible modalities of interaction in this model are expected to occur in two different levels: the physical transformation level and the corrective feedback level. In the physical transformation level, interaction is largely involuntary and subconscious, whereas corrective feedback may occur in a variety of different communication channels. Other concepts such as embodiment, integration and scale of interaction are undefined and design dependent.

For the future purposes of this research, the metaphor of the self-adjusting model is plainly that of self-adaptation (Figure 15). There was little I could find in terms of metaphor to further substantiate this model.

\(^{30}\) Elaboration on the example was done by me.
The next interaction model, the direct manipulation model, has a direct association with the model world metaphor. However, different possibilities of interaction may bring the direct manipulation model closer or further from the world metaphor.

For example, in this interaction model the inhabitant may directly cause the effect in the environment they intend to achieve, such as pushing a wall to make it re-position. In this case, the scale of interaction is one to one, and the interface is the domain of action itself. However, the interaction design might request of the inhabitant the use of abstract gestures for controlling changes, or even the use of a desktop computer interface. These designs would impose different scales of interaction, possibly different levels of embodiment, and certainly different distances in Norman’s (1986) Gulfs of Execution and Evaluation.

The use of extra layers of interface between IA and inhabitant brings advantages and disadvantages. For one, as already suggested, they may require extra steps of domain translations, distancing inhabitants from their goals. On the other hand, a pure application of the world model metaphor necessarily requires an “ontological simplicity” of the action domain (Weller and Hartson, 1993), limiting what is possible to achieve.

Regardless of the interfaces of interaction, Figure 16 illustrates the overall mental model expected of inhabitants in this interaction model.
The next model, the human-like intelligence model, has been already extensively discussed. The metaphor of human-human interaction, presented in section 5.2.4, is integrally pertinent to this model. In sum, it describes an artifact (in this case, a building or architectural space) that shall behave as a person, potentially just like the characters Lightning McQueen in “Cars” (from Pixar, 2006) or Herbie in “The Love Bug” (from Disney, 1968). Although these characters are anthropomorphic cars, not buildings, the analogy may still provide a good understanding of what a functional artifact with human-like intelligence and behaviour can mean. The main distinguishing design factor in these systems, therefore, is that of defining the social role and the personality of the IA system.

I do not wish to be overly redundant in discussing this model. The interested reader may refer back to sections 5.2.4 and 5.3 of this chapter for a revision of the discussion already presented. Negroponte’s (1975) work is perhaps the most instructing material in this subject, and it has also been dispersedly described throughout this manuscript.

Figure 17 illustrates the overall mental model expected of inhabitants in this interaction model.
Finally, the last interaction model to be delineated is that of emergent behaviour. The emergent behaviour model can be exemplified by the metaphor of the coral reef. It is an evolving system that responds to context and inhabitants locally, with no higher-level unified control to coordinate its behaviour towards high-level goals. Instead, the evolution is guided by local responses to local stimuli, and the higher-level conformation of the architecture is the result of emergent behaviour.

Emergent behaviour, or Emergence, “is a process whereby larger entities, patterns, and regularities arise through interactions among smaller or simpler entities that themselves do not exhibit such properties” (Emergence, n.d.).

One interesting development of the coral reef metaphor is that such systems do not completely assume different states to support a new situation. Instead, the situation creates a change in the overall system, which motivates a systemic change. The system evolves from the new situation (instead of towards a higher-level objective), underlying in the idea of evolution that the mark of previous states remain as determinants of the next state.

The emergent behaviour model does not act directly to support inhabitants’ activities. However, it is possible that the incremental changes triggered by inhabitants will give them a feeling of co-creation (Wlaszyn 2011) and ownership, analogous to the construction of informal human settlements. If this is the case, it is possible that some degree of inhabitant agency towards architecture would be fulfilled.
I could not find in literature relevant material to endorse a discussion around a coral reef metaphor. It does not map well to other common metaphors, including the ones already reviewed in previous sections.

Figure 18 illustrates the overall mental model expected of inhabitants in this interaction model.

![Figure 18 - Intended mental model for the emergent behaviour interaction model](image)

It is clear that the definition of the interaction models, as presented so far, does not provide us with sufficiently specific understandings of how each type of IA may work in practice. To this point, every argument regarding the potential impacts of IA on inhabitant agency are just as speculative as they were at the beginning of this thesis.

However, the delineation of the four interaction models provides a framework upon which more constructions that are technically specific may be operationalized. For the purposes of this chapter, and in the definition of “types”, further specifications would prevent the models from being sufficiently representative of the groups identified in IA literature. Instead, the interaction models set the basis for a broader range of possible individual designs, one of which will be described, assembled and tested in the next chapters.

In any of the interaction models, due to the lack of specificities, any individual design will accumulate a number of design decisions in different domains. These decisions, as well as other factors altogether, will in turn influence the relation between architecture and inhabitant in terms of agency.

For reference, and based on what has been discussing throughout this chapter, I propose a list of dimensions that are expected to play a role in how inhabitants should perceive and interact with an IA
system. The list is not directly employed in the evaluation of the IA apparatus developed in the course of this research; however, it served as a guideline of the different dimensions the design should purposefully consider.

5.6 A record of important interaction concepts on inhabitant’s perception of IA

Similarly to Vermeulen et al. (2013), I propose a reference list of dimensions expected to play a role on the research problem at hand. The list summarizes several aspects that have been discussed so far in this document.

Importantly, these interaction aspects focus on the inhabitant-IA interaction after the inhabitant is sufficiently familiar with the functioning of the space. It does not include aspects regarding learning (e.g. how difficult it is to learn how to operate the system) and it also does not include affective aspects related to any form of emotional attachment resulting from continued use.

The dimensions are listed below. They are divided in three groups. Under “personal” are dimensions that refer to a person's intrinsic characteristics that have an influence on perceived valences of empowerment. Under “general” are IA system dimensions that can be measured in any IA system, regardless of use. They refer to the system design and, most importantly, to the way inhabitants perceive the system. Under “task specific” are dimensions that measure the adequacy of the IA system in relation to the goals and tasks performed in a specific situation. Lastly, under “situational preference” are the dimensions that measure the particular predispositions of an inhabitant in a specific time and event.

Because most of these concepts have been already discussed in previous chapters, they will be simply defined in this section.

**Personal**

**Locus of control:** Locus of control is a well-studied concept in psychology. It refers to an individual's overall tendency to believe they can control events affecting them. People with strong internal locus of control will tend to take responsibility for events, e.g. the results of an exam, while people with
strong external locus of control will tend to put responsibility on external factors, e.g. on the teacher. Locus of control may have an effect of a person's perception of agency and control with regard to an IA system.

**Value of environmental control:** Value of environmental control refers to the extent to which an individual personally values having a say on aspects of the environment they find themselves in. Higher appreciation for environmental control is expected to have individuals cultivating such as a goal when opportunity is available; meanwhile, no appreciation for environmental control at all will allow for no connection between control opportunity and empowerment.

**Value of assistance:** Value of assistance refers to an individual's appreciation for third party (spatial) support. It may regard personality traits, such as an individual's preference for carrying activities independent and individually, or for having assistance on tasks. It may also relate to an individual's personal perception of the built environment as inadequate or sufficient for regular activities.

**General**

**Intelligibility of behaviour:** Intelligibility of behaviour refers to how clear and coherent is the system's behaviour to an observing inhabitant.

**Metaphor of interaction:** Metaphor of interaction refers to the overall interaction strategy adopted by the IA system, and how the designers of the system intended it to be apprehended by inhabitants.

**Modalities of interaction:** Modalities of interaction refers to whether the IA system communicates and acts by means of physical response only, or if other modalities are adopted. Modalities can be complementarity, thus using extra channels to tackle intended outcome; or they can be intermediately, thus using extra channels to facilitate communication with inhabitant and improve the adequacy of the physical response.

**Ease of communication:** Ease of communication refers to the level of difficulty perceived by the inhabitant in trying to pass on or retrieve information from the system.

**Levels of embodiment:** Embodiment refers to the extent to which inhabitants perceive the state of computation as being embodied within the architecture or the architectural system/element.
Levels of integration: Integration refers to the extent to which inhabitants perceive the interactive system as being integral component of a building, as opposed to being an add-on system.

Scale of interaction: Scale of interaction refers to the proportion between the inhabitant's input scale as well as the inhabitant's own scale, and the scale of the spatial outcome.

Initiative of interaction: Initiative refers to whether interaction needs to be explicitly requested/initiated by the inhabitant; or if the system will automatically perform as necessary, thus taking the initiative.

Vector of control: Vector of control refers to an inhabitant's perception of control/influence hierarchy between herself, others and the system.

Task specific

Domain of action: Domain of action refers to whether the interactive components of the system are in any way related to the domain of the activity a given inhabitant is interested on. For instance, if the activity of interest is directly related to levels of light (e.g. sleeping) an interactive facade may act in the right domain, because it has the ability to control levels of light. On the other hand, a smart plumbing system will not have the ability to act in the right domain, because nothing in the sleeping activity can be supported by plumbing.

Inhabitant-system goal alignment: Inhabitant-system goal alignment refers to whether the IA system's internal goal is set to assist inhabitants, whether the IA system's internal goal does not involve the interest of inhabitants (e.g. the outcomes benefit a third party and/or doesn't take inhabitant's intentions into account), or whether the IA system's internal goal is in fact set to oppose certain goals of inhabitants (e.g. restrict access to unauthorized areas). In other works, whether the IA system is there to help you, make your life difficult, or it just does not care about you.

Contextual alignment: Based on a system's internal goals, contextual alignment refers to whether inhabitants perceive the behaviour of the system as adequately addressing such goals in the given situation and context. For instance, if the system's goal appears to be: keeping inhabitants comfortable, are the actions taken by the system context sensitive and adequate for the activities taking place in that space?
**Spatial fitness:** Spatial fitness is the concept proposed by Charles Eastman for IA. It refers to the relative amount of effort required (in physical, psychological, social or economic terms) to carry out certain patterns of human activities in a particular environment.

**Perception of task performance:** Perception of task performance refers to the inhabitant's own judgement of performance in any given task.

**Situational preference (at moment of interaction)**

**Engagement preference:** Engagement preference refers to whether, in that particular moment in time, due to any number of factors, the inhabitant would prefer to be engaged with an interactive system or not.

**Control preference:** Engagement preference refers to whether, in that particular moment in time, due to any number of factors, the inhabitant would prefer to hold control or to let go of control of the adaptations taking place in the environment.

It must be mentioned that, as it might have been observed by the reader, the dimensions listed in this section do not focus on the objective design characteristics of the IA system. They focus, more generally, on the inhabitants' perception of the system, of their valued states/tasks, and of the interaction. This operational focus on the perception of the design, rather than on the design objective parameters themselves, has precedents. For instance, Thue and colleagues (2011) focused on the players' perception of the video game design rather than on the technical design specifications that led to player agency. Thus, if certain perception happens by accident or coincidence, it still provides valid information for understanding the phenomena, instead for composing unaccounted error or noise.

Finally, the dimensions listed are presented as a summary of different interaction aspects of relevance to the problem of inhabitant agency in IA. It concludes the literature review on the topic, and demarks the end of the first part of this manuscript. At this point, all the general literature review has been presented, and all the theoretical discussions have been covered.
The next part of this thesis, comprising all of the remaining chapters, will build upon the theoretical basis established so far. It will describe a user-centered approach for design and research in Interactive Architecture, focusing on the relation between interaction and inhabitant agency.
PART TWO: DESIGN, BUILD, TEST
6. Research problem, research questions and research approach

6.1 Research problem

Chapter 6 initiates the second part of this thesis, which, based on the theoretical foundation presented in part one, will demonstrate an approach to explore, empirically, the plausibility of Interactive Architecture’s (IA) claim to foster inhabitant agency.

The approach has its own goals and guiding questions, which are distinct from the overarching goal of this thesis. That is, while the overarching goal relates to applying and testing the new approach, the approach itself requires a well-defined question to be presented at the onset of the process.

The research problem that the new approach is going to tackle, for the purposes of this thesis, has been already discussed in previous chapters. For clarity, it can be summarized and stated as follows: *Inhabitant empowerment is a critical but overlooked aspect of interactive architecture.*

Although empowerment has figured centrally in early debates around IA (see chapter 2), although core concepts of IA extensively support inhabitant agency (see chapters 2 and 3), and although interactivity has been recurrently associated with democratization and empowerment of users (see chapter 4), no empirical evidence currently exists to support these arguments and validate the use of IA in the present architectural landscape.

Again, as already argued, it is important to generate the necessary evidence to inform IA’s development and to support its suitability as a solution for existing demands in architecture. The next chapters will present an approach that is user-centered and evidence-based as a reference to future design and research in the field.

The next section will present the research question the approach will be employed to answer.

6.2 Research question

Based on the gaps and opportunities identified in part one of this thesis, the following research question was set to frame the investigative process described in part two:
How different forms of interaction influence inhabitants’ experience of Interactive Architecture? Can such experiences, rooted in different interaction models, promote inhabitant’s agency and empowerment towards their interactive environment?

Specific hypotheses will be presented when specific experiment designs are introduced.

6.3 Research overview

The research question can only be answered when inhabitants are given the opportunity to experience an IA space and report on their experience. Thus, the first step towards addressing the research question is designing and building an interactive space that can be inhabited.

The next chapters of this manuscript will, in the sequence:

(1) Describe the design process of an IA space;

(2) Test the design concept using a user-centered design method, in order to refine the design concept and to gain further insight on inhabitant’s overall use and experience of IA;

(3) Develop and describe the final apparatus, including the methods to prototype different models of interaction; and

(4) Conduct a user experience study on inhabitant agency in the assembled apparatus, providing a procedural template to data collection and analysis in future research.
7. Designing an instance of interactive architecture

7.1 Overview

In order to carry out this investigation, a new system must be developed that adequately represents the concept of Interactive Architecture and that abides by the types of interaction and experience being studied.

The first, most convenient, and possibly most interesting approach for the current research should be to acquire data from inhabitants of a diverse number of existing interactive buildings. However, as it has been repeatedly argued, the existing examples of IA are very limited in quantity and maturity. They are also not conceived to foster agency, which could likely render uninteresting results.

Given the predicament of this first alternative in the current state of IA development and uptake, the solution is to design, develop and implement appropriate instances of IA to support the user-centered experiments here proposed to address the research question.

This document starts with explaining the main requirements for the IA concept to be developed. Next, it explains the approach to address each requirement individually. Finally, it presents an exploration of design concepts and a preliminary design proposal.

7.2 Initial requirements

The foci of my research, as well as the resources I have available to pursue them, pose a number of initial requirements for the new IA system. The main requirements are stated as follows:

- The possibility of inhabitants to change or influence their architectural spaces in a meaningful way;
- The need to construct an inexpensive apparatus;
- The possibility of inhabitants to interact with their interactive environment spontaneously, thus approximating the experience inhabitants would have with IA in a non-experimental setting;
- The possibility to explore the four interaction models of IA as defined in chapter 5 of this thesis.
Requirements 1 and 2 are addressed together in the following section, given their significant relationship to each other. Next, requirements 3 and 4 are addressed separately.

7.3 An inexpensive IA system that is about core architectural components

7.3.1 An argument for soft architecture

The focus on inhabitant agency towards their architectural spaces implies the possibility of allowing lay users to influence significant components of architecture with ease, in ways that may not be pre-defined. However, the modification or actuation of traditional architectural components, especially flexibly and in real-time, is known to be a difficult and expensive problem to tackle.

The study of IA systems in so-called “hard architectures” is a problem that has been acknowledged since the beginning of the discussions in the field in the 1960’s. Alternatively, designers have chosen to employ new materials, or even new forms of materiality, in order to enable the exploration of IA concepts within reasonable technological and economic constraints.

Brodey (1967) is one of the first to refer to intelligent environments by the name of “soft architecture”. Although his article does not dive in specific forms of execution, Negroponte (1975) points out that Brodey adopted for his explorations a pallet of elements that can be considered literally soft, such as air, light and sound.

To this day, “soft” elements define a considerable number of IA projects. Inflatables and pneumatics, for example, have been used in several IA installations such as Muscle NSA (by the Hyperbody group) and Bubbles (by Michael Fox), as well as in a number of research prototypes (e.g. Khoo et al. 2011). Even water curtains have been employed to redefine space, as a substitute for “hard” materials, such as in the Digital Water Pavillion (by Carlo Ratti).

Considering conventional architecture, which is a composition of solid materials and void, a highly malleable architecture could require the employment of efficient self-assembling nano-robots (Fox & Kemp 2009) which still face a long road of development ahead.

Thus, following the example of others, it appears to be a sensible decision to employ “soft” materials in the development of the present IA system, given the difficulty of making current “hard” architecture not only responsive but also responsive in more than a few predefined ways.
Nonetheless, it must be noted that “soft” materials and/or systems may describe an infinitude of possibilities. The next subsections will explore how “soft architecture” may be used in the current project, and which specific systems may be better suited to meet the requirements at hand.

### 7.3.2 Changing architectural spaces one layer at a time

The definition of an architecture that can modify one or more of its features in response to computational data characterizes what we refer to as Interactive Architecture. However, the idea of built environments that can be modified by human beings in varying scales and time spans is part of a much older and much better explored field than IA. One of its concepts, valuable to this project, is the concept of levels or layers.

In his early work, Habraken (1961) suggested the introduction of different levels of decision making concerning the built environment. He initially defined three main decision-making levels: tissue, support and infill, respectively referring to the urban fabric, the base buildings and their fit-outs. Stewart Brand (1995) has also identified different layers in buildings, which are expected to change at varying timeframes: Site, Structure, Skin, Services, Space Plan, and Stuff.

Habraken’s and Brand’s models have been discussed to further detail in section 4.4.1 of this thesis.

The present project will focus on only one of those levels or layers: Habraken’s infill, or Brand’s space plan, which I consider to be equivalent. They refer to the internal partition of building floors and overall spatial organization of a plan. The choice of this layer alone is justified by several reasons, the main of which are:

- Infill, or space plan, is the layer that more easily and realistically gives itself to the use of “soft” architectural elements;
- The definition of infill layers is more purely related to the concern with inhabitant agency, while outfill layers may also incorporate responsiveness to weather and other external conditions;
- According to Habraken & Teicher (2000), the different layers of the built environment are hierarchical; that is, layers which are lower in the hierarchy can transform without affecting the higher layers, but the opposite is usually not possible; thus by focusing on the lowest layer (infill) I do not need to concern myself with adapting other layers (e.g. structure, site);
- Lower layers pertain to the decision-making domain of fewer people, which allows for more manageable situations during the conduction of the study;
- By reducing number of interacting variables, the use of only one layer allows for a more meaningful analysis of inhabitants’ experience of IA; that is, for whatever results that are reached we can pinpoint them as being fully produced by the action of interactive infills.

7.3.3 Exploring a medium for interactive infill

So far, I have advocated for developing an IA system that focuses on a building’s infill layer and uses “soft” elements in redefining the building’s infill. There are, however, a number of possibilities for the use of “soft” materials in this case. None of them is without disadvantages or figures as an evident best alternative for this project.

The following image (Figure 19) briefly compares different options, including actuated “hard” elements for reference, according to the following criteria: cost (monetary), flexibility (to what extent it can transform and adapt within its domain/function), versatility (whether it can exercise more than one function), and engagement (whether inhabitants can engage with the elements in a natural and/or realistic fashion).
<table>
<thead>
<tr>
<th>Type</th>
<th>Examples</th>
<th>Cost</th>
<th>Flexibility</th>
<th>Versatility</th>
<th>Engagement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuated rigid walls</td>
<td>Wallbot, by Otto Ng (2010)</td>
<td>🟠</td>
<td>🟢</td>
<td>🟡</td>
<td>🟢</td>
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<tr>
<td>Invisible energy</td>
<td>Untitled One, by Sean Lally (2014)</td>
<td>🟡</td>
<td>🟢</td>
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<tr>
<td>Projected pixels</td>
<td>Weightless wall, by Takeuchi (n.d.)</td>
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</tr>
<tr>
<td>Virtual reality</td>
<td>Interactive levels, by author.</td>
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</tr>
</tbody>
</table>

*Figure 19 - Comparison of different strategies for the development of an interactive infill system.*
For this research and for what is feasible to achieve within resource constraints, I can make use of a significant pallet of soft, manipulable materials; or I can simulate the actuation of “hard” architecture in virtually reality, in ways that are yet to achievable in the material world.

Both strategies have positive and negative points. The use of soft elements provides a limited flexibility needed for under-defined behaviours, however it also makes it difficult to create systems that can be read as architecture. Negroponte (1975) endorses a critique to Brodey's work that focuses on the difficulty of grasping the relevance of his “soft architecture” apparatus to architecture in general.

Virtual Reality (VR) also counts with its own benefits and limitations. While it allows for the visual experience of an unimaginable number of IA possibilities, it significantly restrains the engagement of other senses. This difficulty of interaction, especially concerning haptic and kinesthetic feedback, can be a problem in architecture, given most activities taking place in space involve some degree of physical engagement. Furthermore, VR can cause nausea in some people, limiting the duration of experiments and possibly the number of participants to complete the experiments. Despite of limitations, several projects have been finding human behaviour in VR to be equivalent to their real-world behaviour in different situations (e.g. Nee et al. 2015), including the appreciations of architectural settings (Stamps 2010).

I developed a VR application where “hard” IA could be simulated and experienced, using the game engine Unity and the VR hardware Oculus. Figure 20 illustrates an outside view of the interactive building as it could be seen in the stereo VR headset. The building had interactive internal levels (platforms) and partitions, as well as interactive lighting, fenestration and access ramps.

Initial tests were conducted with three subjects. In two of the cases, the subjects suffered from nausea before they were able to complete the 20 minutes task asked of them during the tests. Despite best efforts to improve the comfort level of the application, the problem persisted. The experience also suggested that issues with engagement and spontaneous occupation of spaces could be a difficult problem to solve in this kind of VR environment.

In the end, I decided to explore different options for this research, discarding the use of immersive VR via head-mounted displays as a first alternative.
Unlike the use of “soft” architectural elements, the investigation of IA in VR is still incipient in the field. Adi and Roberts (2010, 2011) present the only examples I have come across where IA in VR is used to test inhabitant’s response to this type of spaces. They made use of a cave automatic virtual environment, thus not needing to address some of the problems associated with head mounts. Nevertheless, their IA setting and interaction was of exceeding simplicity, providing little support for more complex explorations.

Some of the problems with both VR and soft materials can be overcome if solutions in the broader mixed reality continuum are considered instead. If virtual components, such as virtual walls, are brought to the realm of the real world, the incredible flexibility of digital information is maintained, while giving inhabitants the opportunity to occupy the space in unstructured ways and in unrestricted numbers. An example of this kind of interactive space is the “weightless walls” project, by Takeuchi (2012).

Considering flexibility and cost primarily, the use of computer bits and pixels is a greatly attractive alternative to any physical material. The transformation possibilities of bits and pixels are virtually unlimited and cost-free. Additionally they can be transported to the physical world through means of light projection, using a much simpler apparatus than other alternatives would require. The problem
of using projectors, however, is that the utility of the system, or its versatility, is restricted to problems that do not require materiality. This limitation will be further discussed throughout the remainder of this section.

All things considered, the use of overhead projectors to define interactive spaces was the option of choice for the development of the present research.

7.3.4 How 2D projections may create interior 3D spaces

William Mitchel (1990) defines architecture as “the art of distinctions within the continuum of space”, a definition remarkably recurrent in post-modern theory. Hillier and Hanson (1984) explain that “buildings are not just objects, but transformations of space through objects”. Thus, at an infill level, it can be argued that the differentiation and arrangement of internal spaces is the main role of architectural elements. But can this be achieved primarily through two-dimensional marks, textures and colors?

In a conventional building, the differentiation and arrangement of interior spaces is mainly defined by physical walls. However, it is not difficult to suggest that other elements may assume this role. Habraken & Teicher (2000), for instance, present explicit arguments against enclosures being the only ways to define space. They state: “the isolated dolmen erected in Neolithic times still dominates the space around it. Approaching the upright stone, at a certain point we seem to cross a boundary”. Similarly, a countless number of open plan designs make use of furniture clusters and isolated elements to organize space, without employing physical partitions.

The specific use of interactive 2D markings as a primary way to organize space have not been extensively explored yet. Examples exist, such as BIG’s entry for the Audi Urban Future Award (Figure 21), but these works are speculative.
In the wider realm of art, explorations of the concept also exist. One example can be seen in the movie Dogville, by Lars Von Trier, where a small villa is entirely defined by demarcations on the floor (instead of physical walls) and freestanding furniture (Figure 22).

7.3.5 Initial explorations on representing 3D space via 2D images

Two-dimensional images cannot define space by themselves, because space is inherently three-dimensional. Instead, two-dimensional images and projections serve as a signal, a representation of a volume whose definitions are either merely virtual or invisible to varying extents.
The first design concept explorations for projection-based infill spatiality, during the development of this research, was focused on representing different volumes of space as defined by variation in temperature. The heat “pockets” would delimit and differentiate the larger space, creating zones and territories. In turn, the image projections would represent the invisible spaces and their organizations, turning them visible to human eyes.

This concept was largely inspired by Philippe Rahm’s work, a contemporary architect that has been exploring the use of elements such as radiation and pressure as a form of organizing space (Figure 23). However, he only uses these elements generatively and his resulting architecture is static.

![Image](https://example.com/image1.png)

**Figure 23- Example of Philippe Rahm's work with heat and radiation as generative elements. Source: Rahm (n.d.). © Philippe Rahm. Used with permission.**

This first design concept proposal in the present project consisted entirely in the differentiation of space though elements such as heat, light, sound and vibration. The most basic layer of this system was heat due to its ability to form three-dimensional zones and spaces. The other elements are used to reinforce the perception of differentiated spaces and to change the qualities of the architecture created by heat. Figure 24 illustrates this concept.

The image in the left shows a heated space surrounded by cold air. Because air and air temperature is invisible to humans, a projector is employed to make the arrangement apparent. The second image (right) shows the actual space being formed by heated and cooled zones.
Although the heat zones exist in a three-dimensional space, the color-coded light is only projected to the floor, which mitigates the perception of entering a new space instead on stepping onto a floor pattern. Preliminary tests, which will be later discussed, showed that the difference in heat alone assisted in triggering the perception of a three-dimensional zone.

A vibrating vest was also adopted to reinforce the idea of entering a 3D space. Unlike heat, which hardly displays a precise boundary, the vibration can be mapped to a very well defined enclosure. The images below (Figure 25) illustrate the invisible enclosure created by vibration when a person crosses the barrier between spaces. On the left, the visualization of heat is omitted; on the right, it is used to show the equivalence of the heat and vibration layers.
The following images show the test of the prototypical setup for this system (Figure 26). The prototype incorporated both the use of vibration and heat, in order to test whether these elements alone, together with the projection, could evoke a perception of three-dimensional space.

![Prototype test of first design concept.](image)

This first prototype was only tested by the author of this thesis; thus, all the following judgements about it are personal. It was my impression that both vibration and heating contributed to the perception of a three-dimensional space. However, the specific heat-map pattern projected as a representation of space was of ambiguous reading.

The lack of direct mapping between people’s mental models of spatial partitions and the fluid heat-map pattern generated by this initial concept was one of the problems identified. Furthermore, creating, maintaining and manipulating “heat pockets” accurately presented itself unfeasible to the levels required by this concept. As expected, despite its effectiveness in reinforcing the idea of three-dimensionality of a space, heat could not be employed reliably to such end.

The next design explorations that followed this first concept learned from its lessons. While it is possible and even prolific to use secondary elements in the definition of space, such as heat, these can also be limiting. For the sake of flexibility, it was considered a better option to use the projections as a representation of purely virtual spaces. Thus, the projections should stand alone in its capability of defining spatiality, even if other elements are complementarily employed with that aim.

The next section describes a more systematic approach to the exploration of design possibilities.
7.4. Exploring design alternatives for floor projections

There are countless possible designs for a 2D projection onto an open plan space floor, the purpose of which being to organize and differentiate space. These designs express not only aesthetic intentions, but also different possibilities of spatiality and interaction.

I propose that, concerning IA, possibilities of spatiality and interaction (or behaviour) must be the defining aspects by which different designs must be characterized and evaluated. Furthermore, it is apparent to me that these two aspects tend do vary together. The figure below simplify this relation (Figure 27).

![Figure 27 - Relation between spatiality and interaction in two-dimensional infill patterns.](image)

The next page (Figure 28) will present different design propositions and their position in the continuum described above. All propositions are based on an office-building floor that would be ordinarily organized as the baseline condition illustrated.

The two extreme design concepts shown in Figure 26, i.e. the “defined boundaries” and the “multi-layered” concepts, were selected for further exploration. The next section will present the difference between the two conditions and will describe an interaction design for each concept, considering each of the four interaction models established in chapter 5.
Figure 28 - Design propositions in the spatiality/interaction continuum.
7.5. Describing interaction in two opposite design alternatives

The exploration of the different projection designs were based on the concepts’ potential to define spaces and to support specific behaviours (Figure 25). Although the matter of spatiality may be satisfactorily analysed via rendered images, the matter of behaviour is considerably less apprehensible. To begin to study behaviour and interaction in the concepts, I wrote a description of how the systems would work in each case.

This exercise was conducted for each of the design concepts generated during the current exploration. For illustrative purposes, the following table (Table 2) presents the behaviour description of diametrically opposite concepts for comparison. Each behaviour is described considering the four interaction models established in chapter 5.

![Table 2 - Comparative description of behaviour in different projection-based interactive infill concepts](image)

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>TYPE</th>
<th>Phenotype based</th>
<th>Genotype based</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILLUSTRATION</td>
<td>OVERALL DESCRIPTION OF THE TWO SYSTEMS’ DESIGN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Ease of direct control</td>
<td>- Ease of implementing complex behaviour</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Resonance with existing mental models of architectural space</td>
<td>- Higher levels of abstraction and formative possibilities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

130
Users control final disposition through gestures and by directly interacting with boundaries. Computer ensures that output is coherent and gives informational feedback on problematic dispositions, e.g. lack of access.

Users can directly “push” any boundary to make it move. They manipulate specific edges, as well as merge adjacent boundaries. Specific gestures inside a boundary allows for control of heat and sound. Specific gestures also exist for erasure and creation of new boundaries. Eight intuitive gestures must be learned in total. This way, users can easily re-draw the spaces according to need, and they have a very ample power of defining the final internal partition of a building, as long as it is orthogonal.

Users define sets of rules for each layer of territory. Rules are personal. An additional interface is necessary for users to enter their conditional statements.

The rules are layer based, and each layer has two or three possible settings. The layers and settings are defined as follows:

- Type: “In” and “out”
- Heat: “cool”, “average” and “warm”
- Sound: “isolated” and “open”
- Light: “bright”, “medium” and “dark”

Because users cannot give direct phenotypical input, the rules are set using radius and offsets values, as well as anchor points (e.g. furniture and/or person positions).

<table>
<thead>
<tr>
<th>TYPE</th>
<th>Phenotype based</th>
<th>Genotype based</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIRECT MANIPULATION</td>
<td>Users control final disposition through gestures and by directly interacting with boundaries. Computer ensures that output is coherent and gives informational feedback on problematic dispositions, e.g. lack of access. Users can directly “push” any boundary to make it move. They manipulate specific edges, as well as merge adjacent boundaries. Specific gestures inside a boundary allows for control of heat and sound. Specific gestures also exist for erasure and creation of new boundaries. Eight intuitive gestures must be learned in total. This way, users can easily re-draw the spaces according to need, and they have a very ample power of defining the final internal partition of a building, as long as it is orthogonal.</td>
<td>Users define sets of rules for each layer of territory. Rules are personal. An additional interface is necessary for users to enter their conditional statements. The rules are layer based, and each layer has two or three possible settings. The layers and settings are defined as follows: - Type: “In” and “out” - Heat: “cool”, “average” and “warm” - Sound: “isolated” and “open” - Light: “bright”, “medium” and “dark” Because users cannot give direct phenotypical input, the rules are set using radius and offsets values, as well as anchor points (e.g. furniture and/or person positions).</td>
</tr>
<tr>
<td>HUMAN LIKE INTELLIGENCE</td>
<td>Similar functioning as the “perceived direct control” condition above. However, users do not interact directly with the system and they do not need to remember any of the command gestures. Instead, an intelligent entity controls the system. The intelligent entity can</td>
<td>The ability to directly control the definition of rules (such as in the “perceived direct control” condition above) does not belong to the user directly, but to an “intelligent entity”. The “intelligent entity” acts like a person in a con-</td>
</tr>
<tr>
<td>TYPE</td>
<td>Phenotype based</td>
<td>Genotype based</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>HUMAN LIKE INTELLIGENCE</td>
<td>learn about users and might not need instructions or requests for many of the procedures. Otherwise, the intelligent entity communicates with users in a human-human communication fashion, through natural language. The entity works like a human person sitting in a control room overseeing and assisting an operation conducted by a number of human agents in a given space that is controllable from that control room. Of course, technology does not currently exist to support this form of interaction. Wizard of Oz method is required for its execution.</td>
<td>control room in charge of facilitating activities taking place in a given space, and with whom users can talk when necessary. The “intelligent entity” sets the rules of the space according to what it observes and to what the users may request. Communication occurs through natural language, and users do not need to describe the logic of what they want explicitly. Just like with a human person, the communication of intentions or desired outcomes may be sufficient. Of course, technology does not currently exist to support this form of interaction. Wizard of Oz method is required for its execution.</td>
</tr>
<tr>
<td>SELF-ADJUSTING</td>
<td>The self-adjusting model is more rigid than the two conditions above. It offers less possibilities of output and limited opportunity for direct input from users. A standard, base phenotype exists and is adapted depending on use patterns, in a context-aware manner. That is, as users engage in activities, the system recognizes each context and provides the adequate enclosure layout, as well as adequate heat and sound levels, for that specific activity and context. Adequate</td>
<td>A standard, base phenotype + genotype exists and is adapted depending on use patterns. It is a context-aware system, with an established (although evolving) set of genotypic definitions per activity and context. The logic is concerned with functional arrangements depending on activities taking place, similarly to the condition described on the left. The output, however, is not dependent on shared perimeter and each “layer” behaves independently, with its own set</td>
</tr>
<tr>
<td>TYPE</td>
<td>Phenotype based</td>
<td>Genotype based</td>
</tr>
<tr>
<td>------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>SELF-ADJUSTING (continuation)</td>
<td>layout for any activity is established (although evolving) but parametric, so it is responsive to pre-defined parameters (such as number of people participating). The logic of the system is primarily concerned with functional arrangement depending on activities taking place. The output is always based on the drawing of the orthogonal perimeter with confined properties. Users can only give correctional feedback.</td>
<td>of rules. Users can only give correctional feedback.</td>
</tr>
<tr>
<td>EMERGENT BEHAVIOUR</td>
<td>The space presents a rule-based behaviour that considers perimeters in a coherent way. The rules, however, do not refer to functions or fitness, they are merely formal. Users’ interactions in a local scale propagates and influences the system at a larger scale, as a way to adapt to the new parameters and find new stability after the disturbance caused by users. Disturbances/inputs can be: crossing of boundaries, direction of movement, still time, etc. Overall system can also have intrinsic regulating parameters, such as being energy bound.</td>
<td>The overall behaviour of the system is inspired by the behaviour of fluids. Logic is network based and discrete disturbances propagate in a continuous fashion for one specific layer (again, like fluids, for each independent layers). Disturbances/inputs can be: crossing of boundaries, direction of movement, still time, etc. Overall system can also have intrinsic regulating parameters, such as being energy bound.</td>
</tr>
</tbody>
</table>
7.6 A design proposal on interactive architecture

After considerable deliberation, it was decided that the “defined boundaries” concept explored in the previous sections should be selected for further development. The reason for the selection of this specific concept rests on the paramount issues of conceptual clarity and proximity to people’s mental models of infill spaces.

Informal conversations with friends and colleagues proved the concept of “virtual walls” to be easily graspable, while the idea of fluid territorialities was of more distant relation to ordinary concepts such as “rooms” and “partitions”. Since the purpose of this work is to elicit generalizable experiences of interactive architecture, it is especially important for inhabitants to read the projections as representations of infill spaces the way they know them.

It is acknowledged that should systems like this be in common use, they would perhaps be more sophisticated and less reliant on the visual representation of conventional elements (e.g. well). However, for this experiment, immediate legibility is required.

The following images illustrate the different formative possibilities of “virtual walls” and “virtual rooms”, as the boundaries are easily redefined to change the organization of the infill layer of a larger space (Figure 29).
This concept of interactive space-plans, in the context of interactive architecture, is one without built precedents. It is therefore unknown how people would interact with such an interactive infill system, or whether this system would be able to fulfill real-world needs of inhabitants.

Before further developing the concept and implementing it to full scale, a concept-based, anticipated user experience study was conducted. Apart from acquiring valuable data to inform further
development of the concept itself, in a user-centered design cycle, the diary study also shed interesting light on people’s potential relation to interactive environments in their everyday life.

The next chapter describes the anticipated diary study in detail.
8. Anticipated experience diary study: informing further development and implementation of the interactive architecture concept

8.1 Introduction

This study relates to the gathering of information required to assess and substantiate the initial development stage of the IA apparatus, which, in turn, will be later used to evaluate the effects of IA experience on human agency.

The apparatus is conceptualized as an interactive architecture system where a building’s physical walls are replaced by virtual walls. For the purposes of the diary studies, these virtual walls are presented as entities that can be easily created, deleted and re-arranged by users. To prevent cognitive overload of participants, as well as the risk of misinterpretations, no specific forms of interaction or behavior are described. Simply, the system is presented as one that can be easily modified to meet inhabitants’ need.

The diary study was intended to probe the possible uses and potential user experiences of the concept mentioned above. More broadly, it also gathered data and information about people’s perception of an interactive infill space.

It was important that the prototype developed for this thesis was sufficiently functional and engaging from the perspective of users, in order to support the explorations intended for later stages of the thesis’ research. The apparatus design must attend certain levels of usefulness and relevance so that inhabitants feel compelled to interact with the system spontaneously. The problem is that very little is known about when, how and why people would choose to engage with IA systems in their everyday life. It is also unknown whether the specific designs proposed can address real world needs and requirements.

Therefore, in order to assemble an appropriate apparatus for the main investigation, the development of the prototype followed good practices of user-centered design and product development as advocated in literature (Roto et al. 2009, Vermeeren et al. 2010). Most specifically, the current project focused on the anticipated assessment of user experiences, which, based solely on initial product concepts, can be employed at early stages of product development (Sproll et al., 2010).

A literature survey revealed that specific techniques for anticipated user experience studies are still
limited in number, even beyond the realm of architecture, and have not been exhaustively tested. Despite a wider theoretical discussion supporting the importance of user-centered studies in early design concept stages, specific methodologies are less available. Thus, one of the contributions of this thesis lies on applying this type of study to the problem of IA.

It is important to re-state that this study is presented in this thesis with an objective to demonstrate and report on the suitability of this type of approach to the design of IA concepts. The process is commented with regard to adaptations of the original methodology and lessons learned along the way.

The study, titled Anticipated Experience Diary for Interactive Architecture, was carried out with 17 participants and is approved by UBC’s Behavioural Research Ethics Board, certificate number H15-02936. Participants only had access to the conceptual description of the apparatus system, who interacted with the system in imaginary, role-playing situations.

8.2. Research question

The current project intended to acquire information directly from potential users in order to inform the design of the Interactive Architecture (IA) apparatus to be developed. In order to ensure that the new IA apparatus (as well as the sequent experiment design) supports natural situations of use, the research question was stated as follows:

In their everyday lives, when, where, how and why users would choose to engage with an IA system focused on infill customization, given it was a ubiquitous feature in the built environment?

The methods used to address this question are presented in the following section.

8.3. Methodology

8.3.1 Research design

This project explores the potential user experience of an IA building concept. Thus, participants did not have access to any physical prototype of the concept. Instead, participants were introduced to the system’s concept in a video. The participants were asked to imagine their experience with the concept system in their daily routine and to report this experience in diaries. This study is based on the methods
proposed by Sproll and colleagues (2010) for user experience assessment in early product development stages.

The participants who chose to be study subjects in this research were conducted to the following website: http://interacting.space/diary. The website contains all the instructions necessary for participation. Each step in the instructions section of the website can be summarized as follows:

Step 1: Submit signed consent form. Participants are instructed to carefully read the consent form, sign it and submit it to the researchers, either electronically or in paper form.

Step 2: Answer a few questions in a questionnaire. Participants are prompted to fill a questionnaire, whose questions are presented in detail in the instrumentation section of this study proposal.

Step 3: Watch the video. A video explaining the research and the IA system’s concept is presented to participants. Participants are then asked to make use of imagination and imaginative role-playing in their daily routine for one week. More specifically, they are asked to consider that the buildings they inhabit have the capabilities described in the video, and imagine situations when they would engage with those capabilities.

The concept presented (henceforward referred to as “core concept”) was mostly focused on the possibility of (re)creating and (re)arranging internal (infill) spaces and spatial boundaries. The description of the IA system, however, was intentionally vague, and participants were instructed to not limit their imagination to what they assume to be limitations of the system presented. Additionally, participants were told that, apart from being able to re-define internal partitions, they could also control sound and thermal comfort inside each bounded space.

Participants were then asked to imagine the prototype concept in their daily routine. They were asked to imagine as frequently as possible that the buildings they inhabit are instances of the core concept presented, for the period of one week.

Step 4: Submit diary entries. Participants are asked to keep a diary of all imagined uses and situations they have experienced. A template for printing is provided in case the participant wants to keep a handwritten diary. Alternatively, an online electronic form is also made available for participants to submit diary entries as the imagined experiences occur.

Step 5: Wait for the final survey. After one week, a researcher will contact the participant to inform
the 7 days period has completed. Participants are then asked to fill one final survey, composed of open questions, in order to identify potential problems and gather more information on participants’ experiences.

All the material that participants had access to can be found in the aforementioned website.

8.3.2 Sampling
The population of interest to this study is very comprehensive: it includes all persons who inhabit buildings.

The sampling strategy used in this study, however, was opportunistic one. Random and representative sampling is not required, for this study has no inferential ambitions. It is instead interested in qualitative insights from anyone interested in contributing to the research.

This means that the results of the present study must be interpreted with caution. Although the results will accurately describe the anticipated experience of a group of volunteer participants, there is no insurance that this result represents the larger population of all building inhabitants.

In order to ensure a diversity of occupations and geographic locations, a call for voluntary participation was posted online, in social media websites. Specifically, the advertisements was posted in a broad range (as broad as possible) of social media communities known to the author of this study and/or that the author could have access to. Paid advertisements were also divulged on Facebook using the material illustrated below (Figure 30). It is estimated that over 1000 people were reached by the advertisements.
When potential participants were interested in the advertisements, they were directed to a webpage further explaining the project, as well as giving instructions to enroll. Enrollment was considered complete once participants submit a signed electronic consent form, as instructed in the webpage.

8.3.3 Monetary benefits or compensations
There was no monetary benefits or compensations for participation.

8.3.4 Instrumentation
All the material presented to participants are available at http://interacting.space/diary for review.

All the data collection of the study was carried out online, and all participants chose to submit their diary entries via the electronic form available in the website.

For reference, the questions contained in the questionnaire (“step 2”) are copied below.

Q1: What is your age?

Q2: What is your occupation?

Q3: In the scale below, indicate your level of agreement with the following statement: “It is important
to me that I have a say on how my environment should be like” (Likert scale).

Q4: In the scale below, indicate your level of agreement with the following statement: “I prefer to let a computer make decisions about the optimum arrangement of my spaces for me, instead of needing to make decisions myself every time I need a different organization of space” (Likert scale).

Q5: In the scale below, indicate your level of agreement with the following statement: “I prefer to let another person (e.g. an architect) make decisions about the optimum arrangement of my spaces for me, instead of needing to make decisions myself every time I need a different organization of space” (Likert scale).

A paper version of a diary entry page can be found in the appendices (Appendix A), as well as the final survey protocol (Appendix B).

8.3.5 Data collection and analysis
All data was received via electronic forms. The data from the initial survey was graphed and analysed using simple descriptive methods. The analysis of the data from the diaries was initially based on the methodology proposed by Sproll et al. (2010). The methodology was adapted and expended to take better advantage of the data collected and to better fit the context of IA. Further details on data analysis is provided in the results and discussion section.

8.3.6 Protection of Human Rights
When participants chose to be subjects in this study, it was made explicit and clear that participation is voluntary and that participants can choose to withdraw from the study at any time.

All the data collected from participants was protected and encrypted. Participant’s confidentiality was also protected during analysis and publication, by omitting in the documents any information that may allow for the identification of individuals.

8.4 Results and discussion
Seventeen (17) people participated in the first step of the study, which consisted of filling a brief
survey about their personal opinions on being able to control the state of their build environment. The majority of participants (13 out of 17) had between 25 and 29 years old, which reflect the social circles the researcher had easier access to. The sample was very varied in terms of participant’s main jobs or occupations, including attorneys, developers, actors, linguists, engineers, teachers, students and others, and had a balanced proportion of females (n=9) and males (n=8).

The initial survey consisted of a three Likert items, requesting participant’s level of agreement to three different statements. The results and the statements are shown in the image below (Figure 31).

**Figure 31 - Frequency distribution of responses to initial survey**

Most respondents (15 out of 17) agreed or strongly agreed that it is important for them to have a say on their environment. However, respondents were mostly divided regarding whether they would prefer for another entity to make the decisions for them on a regular basis. Although the frequency distribution of responses (Figure 30) may suggest a preference for ceding control to another human being instead of to a computer, the difference is not statistically significant.

Of the 17 participants who started the study, 15 continued to its main component: the diary keeping. Together, the 15 participants submitted 66 diary entries, an average of 4.4 entries per participant.
during a period of one week.

Following the methodology proposed by Sproll and colleagues (2010) for exploring UX potentials at early product development stages, all diary entries were classified according to two aspects. The first aspect is the proximity of the features that participants idealized for fulfilling their needs in the reported experiences to the original concept under scrutiny. Analysis of said proximity allowed us to judge the adequacy of the original concept to different uses and circumstances. The second aspect is the need fulfilled in each reported experience.

Proximity to core concept is attributed to each diary entry according to the scale below:

1. Core concept: “The feature or the need fulfilment item is exactly contained in the original core concept” (Sproll et al. 2010). Thus, without any alteration to the original system design, the participant made use of the system in their daily routine.
2. Similar to core concept: “The feature or the need fulfilment item has similarities with the original core concept” (Sproll et al. 2010).
3. Independent: “The feature or the need fulfilment item is independent from the core concept, but can be integrated into the original core concept” (Sproll et al. 2010).
4. Extraordinary: “The feature or the need fulfilment item has an extraordinary character and cannot be integrated into the original concept” (Sproll et al. 2010).

Proximity to core concept is a main component of this study’s results because the description of the concept, as presented to participants, was intentionally vague. Additionally, participants were encouraged to not be limited by said concept description, and instead imagine the system as it could be in order to fulfill their needs. Therefore, if the core concept is not adequate as is, we should expect considerable departures from it in participants’ reported experiences.

The classification of each diary entry according to the proximity levels presented before was conducted by the author of this thesis (single rater). It is, thus, prone to interpretation and subjectivity. Ideally, to ensure reliability, this type of analysis should be conducted by two independent raters.

Furthermore, proximity levels were defined regarding two different components of the diary entries. Sproll et al. (2010) describe the levels as encompassing both “feature” and “the need fulfilment item” together. It was observed in the present study that these components could be rated separately and differently (i.e. they did not always agree with each other).
For the present study, proximity to core concept was identified (1) in relation to the experience itself, as imagined and described by participants; and (2) in relation to the needs and problems being reported, considering whether they could be satisfactorily resolved by the features of the core concept. As an example, one participant described being able to define glass partitions in real time in order to reinforce territoriality. The described experience itself is not supported by the concept system, because the organization of glass partitions is not among the system’s features. However, it is entirely possible that the need at hand, that of defining territoriality, could have been fulfilled by the concept system’s original features. Thus, in this example, the reported experience of features would have been classified as a level 3 of proximity, while the need fulfillment would have been classified as a level 1 of proximity.

Of the 66 diary entries, 55% (n=36) were classified as a proximity level 1 when considering need fulfillment, while only 39% (n=25) were classified as a proximity level 1 when considering the imagined features as reported. The main outcome of this analysis, however, cannot be conveyed by such aggregated numbers.

The most valuable information provided by this study was the fact that diary entries related to different architectural programs had different degrees of proximity to the core concept. This means that the core concept, which solely refers to the re-arrangement of spaces (e.g. instantiation, size, location), their internal ambiance and environmental levels, may be very useful and pertinent to certain architectural programs but not others (which would require the involvement of more architectural features). The following image (Figure 32) illustrates the total number of entries per architectural program, and the proportions with which the entries employed the core concept without alterations, for both need fulfillment (under “applicable opportunity”) and described feature (under “described experience”).
Figure 32 - Distribution of diary entries per architectural program, proximity to core concept and need/features

Legend:
- Infill space definition in core concept
- Infill space def. outside core concept
- Infill ambience in core concept
- Infill ambience outside core concept
- Environmental comfort in core concept
- Env. comfort outside core concept
- Other outside core concept

Comprehended by core concept
Not comprehended by core concept
It is also important to observe that the different aspects of the core concept - termed infill space definition, infill ambiance and infill environmental comfort - are also not uniformly reported nor uniformly distributed across the different architectural programs. Infill space definition, or the way that internal partitions are organized, is the aspect most recurrently used overall. Again, however, distribution is not uniform across programs. All the architectural programs in which the infill space definition have level 1 of proximity to core concept in over 50% of entries are inherently shared, social spaces: office, living room, pub, library, gym.

The conclusion stated above was not one unexpected at the onset of this study. The redefinition of internal partitions is important in the continuous (re-)negotiation of spaces between the users who occupy it. More specifically, the diary entries revealed that there is often a need to define personal or group territories in shared spaces, to define private “no disturb” spaces, and to re-distribute/re-size space depending on size of groups occupying each area. In contrast, more private spaces such as bathrooms and kitchens required different kinds of features which relate to physical partitions and furniture. Even the bedroom, where 33% of entries were in level 1 of proximity to core concept, these related to either ambience or environmental comfort only.

The following are some statements extracted from the diary entries, which exemplify the social aspect of infill manipulation.

*Participant a:* "The pub is very crowded and the chairs of the different tables are very close together [...]. It would be nice if dividers could be activated between the tables, so that the groups stay more comfortable and the limit of space between tables are respected."

*Participant b:* "I want my colleagues to know that I am very focused and any conversation can break my flow [...]. I open an app that lets me control the system and ask for a private space with a soft red light to indicate that I'm focused and not to be disturbed."

*Participant c:* "Residents of the complex like to come [to the swimming pool+sauna space] in couples or groups of people (when they invite friends for example, like in my case). However, there is only one big space [...]. There is a need for separation of all this spacious room with the swimming pool into several segments [...]. That would create small private areas [...] but still keep the view visible from inside and out."
Several of the 1st proximity level entries in shared spaces also concerned how the number of people in certain spaces should define the relative area occupied by that space.

*Participant d:* "The kitchen/eating area of the place where I work is very small, which prevents all employees from having lunch at the same time. On the other hand, there are empty spaces in other sectors during this time, which are later occupied when people go back to work. [...] I would like to expand the space of the eating area only during lunch time".

*Participant e:* "Meeting room shortage. Combining and borrowing other people's office space to create a larger meeting room."

The examples provided are only a few among many. However they represent what is perhaps the most recurrent opportunities for when and where there core concept is applicable and in line with inhabitants needs.

All the diary entries were also analysed in terms of what are the underlying needs in each reported experience. This is the second main analysis of the diaries’ data. Sproll et al. (2010) suggest the identification of the fulfilled needs according to a general list of basic human needs (e.g stimulation, relatedness, etc). For this study, however, we classified the needs in terms of modification of the built environment, which provided the present study with more meaningful results. The frequency distribution of the needs are shown in the graph below (Figure 33).

![Figure 33 - Frequency distribution of needs, as inferred from diary entry data](image)

NEEDS

- manage spatial resources / modify infill organization
- create/remove physical barrier
- assistive action
- contain noise
- privacy
- fit of thermal conditions
- change ambience
- interface for information/virtual information
- remove distractions
- fit of lighting conditions
- change/improve fenestration
- improve ergonomics
- envelope/outer structure adaptation
- reposition of services

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It is interesting to notice the high frequency of “create/remove physical barrier” and “assistive action”. Together, these needs configure the majority of diaries entries that had proximity levels to core concept of 2, 3 or 4. Respectively, they define needs where physicality is required (e.g. “to prevent the dog from accessing a room”) and where the interactive space deliberately help inhabitants conducting activities (“the space lights up in specific areas to remind me to do a certain task in that location”).

One last quantitative analysis was conducted on the diary data. It refers to whether the experience of interaction imagined by participants involved direct action from users, via varied devices, or whether participants imagined some sort of intelligent or automated system that could act without users’ command. The following image (Figure 34) describes the distribution of entries according to the aforementioned possibilities.

![Use of system intelligence or automation](image)

*Figure 34 - Use of system intelligence or automation*

It must be noted that 6 out of 8 diary entries that mentioned assistive action used system intelligence or automation, a clear overrepresentation. At least one third of automation was used for assistive action.

The methodology presented by Sproll et al. (2010) gives great weight to aggregated data analysis (though diagrams, tabulations and quantitative analysis), overseeing a qualitative appreciation of what
has been reported by the study participants. The authors do not provide a guide for qualitative, case-by-case based learning.

Given the non-representative sample used in the present study, it can be argued that qualitative insights might be even more valuable than the analyses presented so far.

The first search for case-specific information from the data tried to identify anomalies on what participants were reporting. However, the data was very heterogeneous, making it unfeasible to identify outliers. Every diary entry had a very particular context to which the report was pertinent.

The first search for case-specific information looked for any situations that were not already expected or anticipated and that, nonetheless, used features bounded by the core concept. Some of these situations include:

- Creating “ambient moods” for helping persons achieve goals, such as waking up. This could be expanded to a number of situations, capitalizing on the findings of environmental psychology.
- Allowing people to create their own definition of personal spaces, and assuring this is respected.
- Reminding and prompting people for performing tasks by preparing the space accordingly at a pre-specified time.
- Communicating statuses with others, such as personal availability, space availability, objects availability, etc.
- Having the intelligent space automatically finding out best layout arrangement based on criteria provided by participants, e.g. optimize desk arrangement so that the most people can be facing the windows.
- Creating adaptable spaces inside heritage buildings without compromising the original building features.

Although the insights listed above could not be incorporated in the final design, which had a limited space for complexity, they inform the features that would be interesting to include in a more
sophisticated version of the prototype.

8.5 Conclusion and limitations

The anticipated diary study allowed us to answer the following research question: “In their everyday lives, when, where, how and why users would choose to engage with an IA system focused on infill customization, given it was a ubiquitous feature in the built environment?”

Inhabitants mostly used the core concept in shared spaces, in situations where they needed to manage the available space with their peers. They mostly interacted with the space via some form of direct manipulation means, for varied reasons.

It is reasonable to say that the political aspect of architecture, the one that has been the focus of this thesis, becomes evident primarily when social dynamics are salient. In other situations, IA appears to approximate much more the role of a tool, perhaps then sharing more similarities with other types of interactive systems and devices (e.g. automobile).

There are two main limitation in the present study that must be re-stated, in order to allow for a correct interpretation of results. The first limitation is that study participants are not a representative sample of any larger group. Thus, given sample bias, it is possible that studies covering different populations would have very distinct results from the one reached in this study. The other limitation concerns the need to interpret and to classify the data in the diaries, which can be a very subjective process. The use of more than one rater or researcher independently conducting the analysis is the correct way to increase reliability of results. However, for this thesis, the use of inter-rater reliability measures was not possible.

Another minor limitation also refer to the fact that participants are necessarily suggested by the way the concept is presented. Given the lack of direct experience with a prototype, participants must form a mental model based on the descriptions and images provided during the study. This must be taken into account when interpreting the results.
9. The final IA apparatus

9.1 Introduction

The anticipated diary study, reported in chapter 8, provided a validation for the concept of interactive infill based on “virtual walls”, at least for inherently social/shared architectural programs.

The concept tested in the diary study described giving inhabitants the capability of reorganizing internal boundaries, as well as controlling sound and thermal comfort inside each boundary. However, especially in the social or shared architectural programs, most of the experience reports described interaction with infill organization only. Noise and thermal control were less frequent requests and mostly secondary.

Based on this information, the IA apparatus to be developed focused on the interactivity of the infill organization, discarding the features of noise and heat control. Furthermore, the IA apparatus were conceived as a space where multiple people can occupy at the same time, socially.

The apparatus is a prototype of an interactive space plan space. This prototype is different from typical prototypes in IA in the sense that it aims to produce interaction models rather than physical models, primarily.

In order to prevent creating specific expectations about the function of the space, the IA apparatus was simply advertised as “the interactive room”, a multi-purpose space when people can come to “study, play, chill or just have a cup of coffee”.

The following sections will describe the final design and assembly of the interactive room, presenting how each interaction model was prototyped.

9.2 System overview

The fully developed IA setting, called “the interactive room” was assembled in the school of Architecture and Landscape Architecture’s (SALA) building, namely Frederic Lasserre Building, at UBC Vancouver campus. It was installed in a large room (room 309) without fixed furniture, contiguous to students’ studio spaces. The interactive system is intended to act as an interactive infill for that room, further organizing and differentiating interior spaces. It can define interactive interior
boundaries as well as interactive properties for ambiance within each bounded space.

The interactive room is composed by two wall-mounted short-throw projectors assembled with mirrors, a variety of mobile furniture, a curtain separating a control space from the rest of the room, two cameras, and free coffee and snacks available for visitors.

The interactive infill works by defining virtual spaces, mapping them to the real room space, and projecting the location of the “virtual walls” onto the room’s floor via the projectors.

Figure 35 provides an overview of the overall assembly of the interactive room and Figures 36 shows photographs of the actual space (not in function).

Figure 35 - Overview of the interactive room
The main components of the apparatus are the projectors. The short-throw projectors were assembled with mirrors in a specially made mount, and mounted to the wall almost at ceiling height. Located at opposite sides of the room, the projectors could cover half of the floor space each. Figure 37 shows the mounted projectors.

As shown in figures 35 and 36, a black curtain separated an isolated control room, from where the interactive infill could be operated. In order to assist the human operator in the control room, as well
as to track the position of inhabitants (depending on interaction model), two cameras were installed in the room. Figure 38 shows one of the cameras and the control room behind the curtains.

![Figure 38 – Apparatus of the Interactive room. Cameras (right) and the control room (left). Photos by Rohini Nair.](image)

The interactive room counted with three movable desks and chairs; one movable chaise and one movable beanbag chair. Additionally, food and coffee were served on a fixed counter.

Since the interactive infill implies a constant re-organization of space, it did not make sense to have fixed furniture in the room. Therefore, measures were taken to ensure all furniture (except for the counter) was easily mobile (Figure 39). This way, a redefinition of internal partitions can be fully accomplished, via the adequate placement of furniture, as exemplified in Figure 40.

![Figure 39 - Casters on furniture ensure they are easy to re-locate.](image)
UBC students were invited to come and use the space to conduct their usual schoolwork activities, if they would like to do so. Participants were also expected to visit and explore the space out of curiosity or out of wish to contribute towards the research. The space design was not set to endorse a specific use or activity, nor the experiment design. Instead, participants are encouraged to occupy the space as they see fit.

Figures 41 and 42 show the functioning interactive room, with different examples of infill configurations.
Figure 41 - The interactive room. Photo by Rohini Nair.

Figure 42 - The interactive room. Photo by Rohini Nair.
The ways with which inhabitants will interact with such interactive infill space will depend on four different interaction models supported by the apparatus. The interaction models are the ones defined in chapter 5 of this thesis, and are referred to as: direct manipulation model, human like intelligence model, self-adjusting model, and emergent behaviour model. Each of these is described in following sections.

9.3 System behaviour and operation

As already described, the infill partitions are created by projectors mounted near the ceiling, projecting light and color onto the floor.

The projections represent the boundaries of virtual rooms, which can be influenced and/or transformed in different manners, depending on the interaction model employed.

The virtual room, and consequently the mapped projections, are controlled by a computer that was operated by the researcher. All the interaction models, except for the Emergent Behaviour model, used Wizard of Oz method in their execution. This means that an operator was effectively controlling the alterations in the virtual rooms manually. The way the operator conducted the system’s behaviour, however, was different depending on the interaction model being tested, as the operator emulated each specific interaction model accordingly. This was the main method used to prototype the interaction.

The Wizard of Oz method is very common in interaction design and broader user-centered design research. Its assumption is that the full development of the system is not the main goal of this type of research, which is more concerned with users’ perception and experience of that system.

The virtual rooms and partitions are created and controlled in a web application, developed in Javascript by the author. The output image is then mapped to the physical room and projected using two short-throw projectors. The diagram in Figure 43 explain to better detail the entire system.
It must be noted that the system described above could have been simplified by the use of devices such as Matrox’s DualHead2Go. This would preclude the use of the two extra computers connected to each projector.

The control system illustrated in Figure 43 is the same for three of the interaction models: direct manipulation, human-like intelligence, and self-adjusting. Figure 43 also describes how the Wizard of Oz method participate in the overall system for those three conditions.

It can be argued that, in some situations, Wizard of Oz is even preferred to a fully developed and automated system. This is because a complete autonomous system would be required to capture all the necessary input for its operation, interpret that data, and execute the correct behaviour flawlessly. Any errors and delays in this process, which are to be expected in this kind of project, would potentially frustrate users and change their experience. Wizard of Oz, in these cases, allows for an
observation of user experience without the interference of technical limitations and errors.

The only interaction model that does not employ the Wizard of Oz’s method is the emergent behaviour model, which has a different control system. More specifically, instead of a human operator, the entirety of the system’s behaviour in the emergent behaviour model is controlled by a computer software developed by the author.

In the emergent behaviour model, as it will be later explained in detail, the interactive infill responds to inhabitant’s number, position and movement patterns. Therefore, it needs to know the coordinates of all inhabitants at all times. Wizard of Oz’s method would require, in this case, the continuous work of several operators, making it unfeasible.

For the purpose of tracking inhabitant’s position, a system was devised partially inspired by PS Move’s tracking devices. The tracking system developed used two cameras to track the position of glowing spheres inhabitants could wear on their heads, triangulating the final coordinates from the stereo image (Figure 44). The tracking system was developed in Python using OpenCV.

The use of the tracking gear is also a way to simplify a problem in the project, typical of prototypical studies. Ideally, this kind of interactive space would track inhabitants using technologies such as LiDARs coupled with computer vision, which would dispense inhabitants from needing to wear trackers. However, for the purpose of this study, the use of a simpler tracking technique was sufficient.
All of the specific characteristics and behaviours of the interactive room, under each of the interaction models, will be further described in the next sections.

9.4 Self-adjusting interaction model

In the self-adjusting interaction model, the system can recognize and identify each context and each activity taking place inside the space. After activity is identified, the system provides the adequate enclosing area for that activity, as well as adequate ambience and lighting levels.

Adequate layout for any activity is pre-established (although it can evolve via correctional feedback).

*Figure 44 - Tracking system overview*
and parametric (thus sensitive to context, such as the number of people participating in given activity). The logic of the system is primarily concerned with functional arrangement depending on activities taking place.

This interaction model follows the following logic flow: (1) to identify which activity is taking place, (2) to identify contextual parameters for that activity, such as number of people involved, (3) to define adequate area, lighting and color based on activity and parameters, (4) to constantly check for changes in activity and parameters, adapting accordingly, (5) to constantly check whether the last change performed received correctional feedback, (6) if correction is flagged, undo changes, record learning data and re-run logic flow. Any change in the room always follows these steps. In the current setup, these steps are followed by a human operator, using a Wizard of Oz method.

Figure 45 illustrate the instructions provided to inhabitants for how to interact with the interactive room, under a self-adjusting interaction model.

Figure 45 - Instructions for interacting with the interactive room, under a self-adjusting interaction model
Figure 46 exemplifies the response of the interactive room when an inhabitant occupies it. In the example, the inhabitant enters the interactive room (a) and heads towards the counter for coffee and snacks (b). The space by the counter is minimum, but it expands as it is identified that the inhabitant has entered that space and is occupying it while eating a few snacks. When the inhabitant leaves the eating area towards the lounge space, the eating area retreats while the lounge space expands (c). Next, when the inhabitant moves one of the desks away from the wall, the internal partitions update to better accommodate the new location of the desk and of the inhabitant (d) (e). The inhabitant claps once to indicate required correction. The room then re-runs the steps for self-adjustment, but this time reaching a different configuration than it did the first time, given the learning process (f). Next, when the inhabitant decides to use a larger space for conducting manual tasks, joining two desks together, the interactive infill once again updates to the new activity and context (g) (h). A larger space is defined around the desks and better lighting is provided for the conduction of the manual tasks (i).
9.5 Direct manipulation interaction model

In the direct manipulation interaction model, inhabitants control the final disposition of infill partitions through gestures and by directly interacting with spaces and boundaries. The system then checks if output is coherent and gives informational feedback on problematic dispositions, e.g. lack of access.

The system may also give general feedback during every interaction, informing inhabitants of general data (e.g. room size, percentage of total space taken by room, electricity consumed by room size and light levels, etc) and known consequences for specific design decisions. However, in the interest of simplicity and for the purposes of this research, feedback was limited to the identification of potential layout problems.

Figure 47 presents the set of gestures inhabitants could use to manipulate the interactive infill. Most gestures allow inhabitants to act directly on the world domain, e.g. inhabitants can directly “push” any boundary to make it move. Other gestures cannot be mapped directly to what they are meant to control; however, relational proximity was attempted. Using the set of gestures provided, inhabitants can easily redraw the spaces according to their need, and they have a very ample power in defining the final internal partition of the space.

Figure 48 show an inhabitant re-defining the infill configuration of the interactive room via the set of gestures provided.

Finally, Figure 49 demonstrates an instance in which a problematic layout triggers a feedback from the system, instructing the user about the potential complication.

Due to difficulties in implementing gesture control in this scale, and because the technical resolution of these difficulties are not the focus on the present study, the direct manipulation interaction model is emulated by a human operator using Wizard of Oz method. Gestures are observed via cameras installed in the room and the commands are translated by the operator into the control application developed by the author.
Figure 47 - Instructions for interacting with the interactive room, under a direct manipulation interaction model
Figure 48 - Example of inhabitant-room interaction under the direct manipulation interaction model. Photos by Robini Nair
9.6 Human-like interaction model

In the human-like interaction model, inhabitants interact with an intelligent room, which in turn can make changes to its own infill organization. Interaction occurs via natural language, and any requests to the room can be made as if talking to a human being. Thus, no machine-like commands are necessary. Instead, higher-level commands and conversations can be established successfully.

Figure 50 illustrates the instructions that were given to inhabitants so that they could interact with the interactive room.

Once again, Wizard of Oz method was used to emulate the interaction model behaviour. Wireless speakers were installed in the room and the human operator orally communicated with inhabitants using a voice synthesizing software.
Figure 50 - Instructions for interacting with the interactive room, under a human-like intelligence interaction model

Figure 51 illustrates one interaction between an inhabitant and the “intelligent room”. Notice that in the example the inhabitant does not need to tell the room the exact steps it must take to achieve the desired outcome. Instead, the request is made in a much higher level, in a way that it could have been made to another human being.
Figure 51 - Example of inhabitant-room interaction under the human-like intelligence interaction model.

9.7 Emergent behaviour interaction model

The last interaction model to be described in this chapter is also the most complex one. The emergent behaviour model needs to be described in terms of its internal generative logics, given it does not follow a higher purpose behaviour.

Because the outcome of interaction in this model is a result of a number of smaller, local interactions, the transformation of the interactive infill cannot be emulated by a human operator using a Wizard of Oz method. A human operator could not possibly account for the complexity of this kind of behaviour.

It must be noted, however, that the emergent behaviour interaction model can encompass an infinity of different forms of interactions and behaviours. This description in only one in a very vast and very
diverse array of possibilities.

The design of this specific instance of emergent behaviour IA is based on the dynamics of underlying invisible cells (Figure 52). Each cell has a center and a diameter and it competes with the other cells for space. The cells cannot occupy the same space, thus they push each other away in local interactions.

*Figure 52 - The underlying logic of the emergent behaviour interaction instance*
Without the presence of inhabitants, the cells will continue to interact with each other, trying to find stable positions. The presence of inhabitants, however, causes disturbances to the system, influencing the overall dynamic. The specifics of how the cells react to the presence and movement of inhabitants will soon explained.

However, it is first necessary to explain how the internal partitions, or the infill organization, of the interactive room is defined based on the disposition of the invisible underlying cells. The infill partition of the interactive room is a Voronoi diagram that uses the cells’ centroids as its generative seeds.

A Voronoi diagram is a partitioning of a plane (in this case, the entire floor area of the interactive room) into regions based on distance to points (or “seeds”) contained in the plane. Each seed defines a region consisting of all points closer to that seed than to any other seed on the plane. On Figure 52, the Voronoi diagram is drawn in cyan, and the seeds are identified as the center of the underlying cells. Each of the Voronoi’s regions configure a Voronoi room in the interactive infill.

The movement and travel patterns of inhabitants inside the interactive infill influence the lighting and the color of the Voronoi rooms. When an inhabitant leaves a room, that room gets darker while the room that has just been entered lights up. Regarding colors, all Voronoi rooms will tend to reach a calm shade of blue. However, high movement levels inside a room will cause it to “stir” and reach increasingly warmer colors, such as red. Again, upon rest, the color will try to return to the cool shades of blue.

Apart from color and brightness, inhabitants also influence the position and behaviour of partitions by disturbing the dynamics of the underlying invisible cells that define the formation of the Voronoi diagram. When inhabitants enter a new room, the underlying cell correspondent to that room will inflate (“stealing” from its neighbours) and gain more “strength” in pushing the other cells away. This causes the Voronoi room to increase in size and forces the other cells to re-accommodate.

Inhabitants, however, do not have access to the information of how the underlying logic of the system works. Instead, they can only perceive the emergent behaviour of the system (thus the name). Figure 53 shows the instructions provided to inhabitants on how to interact with the room.
Figure 53 - Instructions for interacting with the interactive room, under an emergent behaviour interaction model

Figure 54 exemplifies the behaviour of the system based on the activities of three inhabitants. The photos in Figure 54 were taken 5 seconds apart from each other.
Figure 54 - Example of inhabitant-room interaction under the emergent behaviour interaction model.
10. Inhabitant experience and empowerment in Interactive Architecture: an exploratory study

10.1 Introduction
With an IA apparatus that supports the use of the four typical interaction models for IA, it is now possible to conduct a user experience study to test inhabitant agency in relation to interactive spaces. This chapter describes a study that can be used in later stages of IA concept development in order to assess its potential to fulfill its fundamental claims.

This study is based on all the precedent discussions introduced to far. It has an ambition to provide initial answers to the research question framing the part two of this thesis. However, its main objective is to test the user-centred approach proposed and report on the problems and opportunities encountered along the process, laying the basis for later similar studies.

The study presented in this chapter is a pilot study and must be interpreted as such.

10.2 Research question
As already stated, the research question guiding this study is the following:

How do different forms of interaction influence inhabitants’ experience of Interactive Architecture? Can such experiences, rooted in different interaction strategies, promote inhabitant’s agency and empowerment towards their interactive environment?

The experimental method used to address this question is presented in the following section.

10.3 Methodology

10.3.1 Research design
Based on design concept explorations and an anticipated user experience study (unpublished, UBC BREB Number H15-02936), the current research built an Interactive Architecture experimental settings and invited participants to occupy it. Different groups of participants used and tested four different models of interaction with the IA system. Thus, this experiment had a between-subjects
design, aka independent measures.

One of the main research design decisions faced in this study related to either conducting a highly structured within subjects study or a non-structured between subjects study.

A non-structured between subjects study would allow people to come and go in the space, whenever they wanted, occupying it the way they’d see fit according to their needs and intentions in the space. The advantage of this design is that it would favor natural situations of use. People would be able to come and occupy the space in a way similar to when they occupy architectural spaces (e.g. office, home) in their daily routine.

The downside of this approach is that it would require a very large number of participants, for two reasons. One of the reasons is that between subjects study designs are known to require more participants, given the total number of participants are split among the different conditions being tested. The other reason is that the non-structured procedure for participants would allow for many different kinds and durations of occupancy, resulting in a less consistent data set. More participants are then needed to compensate for the variations.

A structured within subjects study, on the other hand, would require less people, since the same group of people would be able to test all the study’s conditions. However, it would require a greater commitment from the group of participants, since they could not just come at any time, for any purpose, and to any duration, and since they would have to return for four different days to experience all the test conditions.

Nonetheless, the fact that participants would be able to compare and discuss their experience regarding different models of interaction could provide much more rich qualitative insight than the alternative. The downside of this approach is that it would not be able to afford natural situations of use. It would require, instead, a specific protocol to be followed, such as a list of tasks for participants to complete each day. There are also known problems with within-subjects designs for measuring specific variables, given participants are influenced by previous experiences of previous test conditions. This can be partially mitigated by random order of participation and temporal distance between test days.

The very social aspect of the interactive space-plan concept, as made evident by the diary study, was the element to determinate the choice for the present research. Different forms of social association
and space negotiation could be discouraged in the structured study design, or fail to happen altogether. Additionally, in the structured within subjects design, people’s participation in the study would need to be scheduled and organized in groups, which could pose many technical difficulties. In the end, the non-structured between subjects design was elected for this study.

Participants filled questionnaires prior and after experiencing the space. The first questionnaire probed participants regarding personal characteristics and preferences that could play a role in their perception and attitude towards the interactive space. The last questionnaire asked participants about their experience of the space (using established UX survey material), plus specific questions designed to inquire about participants’ perception of personal agency towards the space (based on self-efficacy and self-determination theories). In between these two surveys, participants were left free to occupy the space in whatever way they wanted.

Participants were observed during their use of the space. Aspects such as whether participants choose to use the system features, and the situations when they choose to do so, were recorded in written form.

10.3.2 The interactive architecture setting
The IA system has been already described in detail in the previous chapter. It was presented separately in order to maintain its relation to the diary study, a user centered design method that assisted in the definition of the final concept, and to allow for a more lengthy description of the prototyping process. The reader may refer to chapter 9 to review the description.

10.3.3 Sampling and recruitment
Participants for the current study were mainly recruited among students who ordinarily use Lasserre building, as well as other students from the School of Architecture and Landscape Architecture (SALA). Opportunistically, other UBC students were also invited to participate.

Recruitment to participate occurred in two different ways. The first one was anticipated advertisement, in which case banners were publicized in SALA’s buildings up to two weeks prior to the beginning of the study. Advertisements were also published in an internal bulletin for students at SALA and shared
on social media pages associated with SALA students. Anticipated advertisement was intended to target students and staff that may be interested in the study and interested in scheduling their participation for when the Interactive Room was available.

The second form of recruitment took place during the days when the experiment was running. It consisted of banners and branding inviting passers-by to enter the space and participate in the research.

10.3.4 Monetary benefits or compensations
There was no fixed monetary benefits or compensations for participation. However, snacks and coffee were being served at no cost for participants. Furthermore, after completing participation, participants were entered in a prize draw for the chance of winning $100 CAD.

10.3.5 Instrumentation and data collection
Data collection took place through: (1) initial questionnaire, (2) experience questionnaire, and (3) observation notes. Both the questionnaires and the observation protocol can be found in the Appendices (Appendices C, D and E, respectively).

All the raw data is being kept in UBC Vancouver campus in the principal investigators’ computer. After analysis, data was stored in encrypted files.

10.3.5 Protection of human rights
When participants choose to be subjects in this study, it is made explicit and clear that participation is voluntary and that participants can choose to withdraw from the study at any time. Participants are requested to read and sign a consent form prior to participation.

All the data collected from participants was protected and encrypted. Participant’s confidentiality was also protected during data collection, by omitting in the data any information that may allow for the identification of individuals. No record was kept of the video captured by the cameras installed in the room. The video was only be streamed locally in real time, not recorded.
10.4 Results and discussion on the data collected

The analyses presented in this section are intended as a template to demonstrate how to analyze and present the data collected during the inhabitant experience study described so far in this chapter. Because this is a pilot study, and due to methodological limitations, the data collected cannot be considered sufficient and satisfactory evidence to answer the research question. However, it demonstrates how future research will be able to do so.

The study counted with 30 participants in total, divided into four groups in a between-subjects experiment design: self-adjusting room group (n=8), direct manipulation room group (n=8), human-like intelligence room group (n=7) and emergent behaviour room group (n=7).

Of the 30 participants, only 13 filled the initial survey online. From the 13, it was only possible to link the data from initial and post-occupancy surveys in three instances, because most participants did not fill the identification field in the post-occupancy survey. Therefore, it was not possible to investigate the relation between the user experience of the interactive room and participants’ previous attitudes towards the capability of control over one’s environment.

Nevertheless, the initial survey indicated that most participants are students (13 out of 13) who fall within the age group of 25 to 29 years old (9 out of 13). As shown in figure 55, they largely value independence and having a say on how their environment should be like. They also prefer choosing and customizing their own environment than ceding that power to either a machine or another human being. There is no difference between acceptance of ceding control to a human or a machine in the sample.
Figure 55 - Frequency distribution of the answers to the Likert scale items in the Initial Survey.

On average, as self-reported, the 30 participants who visited the interactive room spent 15.18 minutes inside the room (SD = 7 minutes). During that time, they tried to interact with the interactive room in average 11.86 times (SD = 10.31). These numbers vary each day as described in the table below (Table 3).

<table>
<thead>
<tr>
<th>Interaction mode</th>
<th>Reported time spent inside the room</th>
<th>Reported number of interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (min.)</td>
<td>Standard dev.</td>
</tr>
<tr>
<td>Self-adjusting</td>
<td>15.83</td>
<td>12.42</td>
</tr>
<tr>
<td>Direct manipulat.</td>
<td>16.25</td>
<td>6.94</td>
</tr>
<tr>
<td>Human-like int.</td>
<td>20.00</td>
<td>8.66</td>
</tr>
<tr>
<td>Emergent behav.</td>
<td>12.14</td>
<td>3.93</td>
</tr>
</tbody>
</table>

People tended to spend more time in the Human-like intelligence room, despite that being the room with which they interacted the least. As expected, due to the nature of the interaction mode, the direct manipulation room was the one with the higher number of interactions. A one-way analysis of variance (ANOVA) test showed the difference in the number of interactions between the groups to be statistically significant (F=3.206, p=0.043). A Tukey post-hoc test, which compared groups in pairs

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31 All of the following assumptions were met: the dependent variable is measured at the ratio level (i.e., it is continuous); the independent variable consist of categorical, independent groups; there is independence of observations; there are no significant outliers; the dependent variable is approximately normally distributed; and there is homogeneity of variances.
rather than comparing all groups together, revealed that the difference in number of interactions was statistically significantly only between the Direct Manipulation and the Human-like Intelligence groups, and only admitting a liberal level of significance (p=0.056). There was no statically significant difference between other pairs of groups and in considering time spent in the room as a whole.

The short periods of time that participants spent inside the interactive room, alongside the high density of interaction (average of one interaction every 1.28 minutes), portrays a pattern that has been observed in the field. That is: most participants would come to the interactive room to explore the space as a primary intent, not to develop other daily activities inside the space provided.

This observation defines a significant limitation of this study. Any insight derived from the present study must be considered as primarily concerning a first exploratory interaction between an inhabitant and an unfamiliar type of interactive architecture. The results cannot say anything about the continued use of an interactive space for daily activities. Future studies must consider surveying the use of interactive spaces for an extended period of time, allowing inhabitants to get used to the room. They should also consider allowing this cognisance period to occur outside the umbrella of a research study, for the condition of being a research subject may have greatly contributed to the way participants apprehended the space and behaved inside the room.

The sequence of figures presented ahead describe the frequency distribution of participants’ answers to each Likert-scale item in the user experience survey (Figure 57 to Figure 77).

For clarity of the results, the size of the distribution bars has been normalized so that 100% of the respondents for the self-adjusting room and for the direct manipulation room measure exactly as much as 100% of the respondents for the human-like intelligence room and for the emergent behaviour room. This way, despite the fact that the first two rooms count with 8 participants each and the last two rooms count with 7 participants each, their results can be compared. Thus, the sizes of the bars are set in percentages, notwithstanding each bar being composed of blocks representing individualized answers. All figures must be interpreted using the following legend (Figure 56).
**AGENCY AS “TO CAUSE AN EFFECT IN THE WORD”**

**S1 - “I felt that I could influence the Interactive Room with my presence or my actions”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

**SELF-DETERMINATION’S CONCEPT OF AUTONOMY**

**S2 - “I caused changes to the space in the room because these changes interested me”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

---

**Figure 56** - Legend to be used to interpret Figures 55 to 75

**Figure 57** - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 1 of the user experience survey.

**Figure 58** - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 2 of the user experience survey.
**Figure 59** - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 3 of the user experience survey

**CONTROL**

**S3 - “I feel I have control over my environment in this room”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

**Figure 60** - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 4 of the user experience survey

**MEANING**

**S4 - “I can have the space personalized in a way that is meaningful to me”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

**Figure 61** - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 5 of the user experience survey

**USABILITY**

**S5 - “It was easy to use and interact with the Interactive Room”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour
PLACE IDENTITY

S6 - “By the time I left the Interactive Room, I believe it reflected who I am to some extent”

Self-adjusting

Direct manipulation

Human-like

Emergent behaviour

Figure 62 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 6 of the user experience survey

ATTACHMENT

S7 - “I feel some level of attachment to this space after using it”

Self-adjusting

Direct manipulation

Human-like

Emergent behaviour

Figure 63 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 7 of the user experience survey

AUTHORSHIP

S8 - “I am happy to take credit for the current state of the Interactive Room. I helped creating it”

Self-adjusting

Direct manipulation

Human-like

Emergent behaviour

Figure 64 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 8 of the user experience survey
**OWNERSHIP**

**S9 - “I have a feeling that the spaces that came into being because of me inside the Interactive Room are mine. They belong to me”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

*Figure 65 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 9 of the user experience survey*

**FLOW**

**S10 - “I interacted with the space spontaneously and automatically without having to think”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

*Figure 66 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 10 of the user experience survey*

**GENERAL EXPECTATION**

**S11 - “I expected more from the experience”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

*Figure 67 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 11 of the user experience survey*
ENGGAGEMENT EXPECTATION
S12 - “I expected the experience to be more engaging”

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

Figure 68 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 12 of the user experience survey

AESTHETIC EXPECTATION
S13 - “I expected the aesthetic experience to be better”

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

Figure 69 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 13 of the user experience survey

ENJOYMENT
S14 - “The experience was enjoyable”

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

Figure 70 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 14 of the user experience survey
**COMPETENCE (SELF-EFFICACY)**

**S15 - “The experience made me feel competent”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

*Figure 71 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 15 of the user experience survey*

**EMPOWERMENT**

**S16 - “The experience made me feel powerful”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

*Figure 72 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 16 of the user experience survey*

**NERVOUSNESS**

**S17 - “The experience made me feel nervous”**

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

*Figure 73 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 17 of the user experience survey*
ANNOYANCE

S18 - “The experience made me feel annoyed”

<table>
<thead>
<tr>
<th>Self-adjusting</th>
<th>Direct manipulation</th>
<th>Human-like</th>
<th>Emergent behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 74 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 18 of the user experience survey

BOREDOM

S19 - “The experience made me feel bored”

<table>
<thead>
<tr>
<th>Self-adjusting</th>
<th>Direct manipulation</th>
<th>Human-like</th>
<th>Emergent behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 75 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 19 of the user experience survey

PRESENCE OF THE MEDIUM

S20 - “I was completely focused on my personal activity inside the room, not paying much attention to the environment or the room”

<table>
<thead>
<tr>
<th>Self-adjusting</th>
<th>Direct manipulation</th>
<th>Human-like</th>
<th>Emergent behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 76 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 20 of the user experience survey
FLOW

S21 - “I felt that inside the Interactive Room the way time passed seemed to be different from normal”

- Self-adjusting
- Direct manipulation
- Human-like
- Emergent behaviour

Figure 77 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 21 of the user experience survey

The figures show that all the proxies being used to understand human agency scored from balanced to high agreement across interaction models: basic agency (as in being able to cause an effect on the world), autonomy (based on self-determination theory), competence (based on self-efficacy theory) and empowerment. Figure 78 provides a brief comparison of the four measures.

Figure 78 - Comparative of measures of basic agency, autonomy, competence and empowerment

The large majority of participants agreed that they could influence and/or cause changes to the interactive room. They also agreed that they caused the changes because these changes interested them. Levels of agreement dropped when participants were asked directly whether their felt competent and powerful. Interestingly, especially regarding competence and empowerment, levels of agreement seemed to vary considerably depending on the model of interaction. Statistical analysis comparing the results between the different models of interaction will be presented in next pages.
It can also be pointed out that, based solely on a visual study of the graphs, the self-adjusting model appears to be the one with the lowest indicators in all measures of agency, whereas direct manipulation appeared to be the one with the highest.

It is also interesting to notice that aspects considered to be directly influenced by agency do not seem to consistently respond to variations in responses to the previously mentioned indicators (Figure 79).

![Figure 79 - Comparative of measures of meaning, place identity, attachment, authorship and ownership](image)

For more significant results, different statistical analyses were carried out on the survey’s data. The first analysis was the Kruskal-Wallis H test (also called "one-way ANOVA on ranks"). This test is a nonparametric method that can be used to test whether there are statistically significant differences between two or more groups of an independent variable, such as the different interaction modes in the interactive room, on an ordinal dependent variable, such as the Likert-scale items in the user experience survey.

Next, the four interaction modes are grouped in two groups and re-analysed with the method mentioned above. The two new groups are: (1) direct input group, containing the Direct Manipulation and the Human-like Intelligence interaction modes; and (2) indirect input group, containing the Self-Adjusting and the Emergent Behaviour interaction modes. The hypothesis is that regardless of specific methods, the modes in which participants are able to specifically determine the outcome of the interactive room would elicit different experiences than the ones in which participants are not, especially regarding agency and empowerment. Thus, in this analysis, the independent variable is whether participants could directly define the outcome or not.

Finally, I carried out a cumulative odds ordinal logistic regression with proportional odds on the data.
This test is used to predict an ordinal dependent variable given one or more independent variables. It is used in this study to find out whether different items in the survey are correlated, and if participant’s response to one item can be predicted by their response to a different, independent item. All analysis are conducted using SPSS Statistics software.

Using p=0.05 as the cut reference, the Kruskal-Wallis H test showed that there was a statistically significant difference in responses among the different interaction modes in three of the survey’s items.

There was a statistically significant response to the statement S11 (“I expected more from the experience”) among the tested groups, \( \chi^2(2) = 8.270, p = 0.041 \), with a mean rank of 22.38 for Self-Adjusting room, 13.19 for Direct Manipulation, 10.86 for Human-Like Intelligence and 14.93 for Emergent Behaviour.

There was a statistically significant response to the statement S17 (“The experience made me feel nervous”) among the tested groups, \( \chi^2(2) = 12.001, p = 0.007 \), with a mean rank of 17.25 for Self-Adjusting room, 12.56 for Direct Manipulation, 23.50 for Human-Like Intelligence and 8.86 for Emergent Behaviour.

There was a statistically significant response to the statement S18 (“The experience made me feel annoyed”) among the tested groups, \( \chi^2(2) = 8.986, p = 0.029 \), with a mean rank of 18.75 for Self-Adjusting room, 13.13 for Direct Manipulation, 20.71 for Human-Like Intelligence and 9.29 for Emergent Behaviour.

It must be noted that, as could have been expected, the interaction mode in which participants had to speak to the room is the one that made participants feel more nervous and annoyed. Yet, this same Human-Like Intelligence interaction mode is the one where participants reported least disappointment with the experience.

It can also be added that, given a less conservative p value than the one adopted in this analysis, response to the statement S1 (“I felt that I could influence the Interactive Room with my presence or my actions”) among the tested groups could also be included in the significant results. With \( \chi^2(2) = 7.585, p = 0.055 \), a mean rank of 10.31 for Self-Adjusting room, 20.25 for Direct Manipulation, 14.00 for Human-Like Intelligence and 17.50 for Emergent Behaviour; it is possible that a larger sample size would find statistically significant differences between the groups regarding this statement.
The second round of analyses created a new independent variable by combining the interaction modes into whether or not the interaction mode allows participants to directly define the outcome of the interactive room. For most of the survey’s items, creating these two groups caused the difference between groups to reduce rather than increase, with two notable exceptions: competence and empowerment.

There was a statistically significant response to the statement S15 (“The experience made me feel competent”) among the two groups, $\chi^2(2) = 5.084$, $p = 0.024$, with a mean rank of 12.07 for the indirect group, and a mean rank of 18.93 for the direct group. Figure 80 illustrates the difference per group.

Statement S16 (“The experience made me feel powerful”) also increased effect size and significance considerably after the grouping, however with $p=0.12$ it remained not statistically significant.

**COMPETENCE (SELF-EFFICACY)**

**S15 - “The experience made me feel competent”**

![Figure 80 - Per group comparative frequency distribution of levels of agreement (in Likert scale) to statement 15 of the user experience survey](image)

Additionally, after the grouping, the statistically significant difference between groups regarding S11 (“I expected more from the experience”) remained, $\chi^2(2) = 4.996$, $p = 0.025$, with a mean rank of 18.90 for the indirect group, and a mean rank of 12.10 for the direct group. However, the grouping annulled the significance previously found concerning other statements.

Finally, one more statistically significant item emerged after grouping. With $p = 0.049$, participants’ response to the statement S20 (“I was completely focused on my personal activity inside the room, not paying much attention to the environment or the room”) differed between the two groups, $\chi^2(2) = 3.867$, with a mean rank of 18.50 for the indirect group, and a mean rank of 12.50 for the direct group.

This evidence suggests that whether or not the interaction mode allows participants to directly define
the outcome of the interactive room can have an influence on whether or not inhabitants feel competent and, potentially, powerful. More research is needed to generate stronger evidence for or against this claim.

Either way, it is interesting to note that a same phenomenon (i.e. effect size being larger when considering direct vs. indirect action) is not observed on participants’ perception of control, autonomy, attachment, authorship and ownership. The revised literature have created the expectation that these different items could have an influence on each other.

In order to further investigate the interdependence between the items of the survey, an ordinal regression test was conducted. More specifically, it was used a cumulative odds ordinal logistic regression with proportional odds, and the independent variables (likert-scale items) were treated as interval variables. The only significant association found was the one between competence and empowerment. An increase in accordance to feeling competent was associated with an increase in the odds of feeling powerful, with an odds ratio of 8.413 (95% CI, 1.940 to 36.474), Wald $\chi^2$(1) = 8.098, $p = 0.004$. Again, no such association was found between participants’ perception of control, autonomy, attachment, authorship and ownership.

As already stated, the main purpose of this study was to test and demonstrate its application in the context of IA research, learning from the process. The next chapter will discuss the lessons learned to further detail, summarizing and commenting on the contributions of this work. It will also condensate a set of recommendations for future research.
11 Conclusion

11.1 Main contributions
This thesis took an important first step in assembling, testing and demonstrating an inhabitant-centered approach for research and design in Interactive Architecture (IA). This is a much-needed contribution, as it seeks to address a critical gap in the field. As already discussed, a few authors highlight the need for user-centered methodologies in IA (e.g. Achten and Kopřiva, 2010), yet, to the best of my knowledge, there are no reported applications of user-centered and evidence-based techniques to research and design in the field (Costa Maia and Meyboom, 2015).

Established user-centered design techniques needed to be studied in the context of IA for a number of reasons. For one, each available technique is usually only applicable to a narrow range of situations and must be employed accordingly (Vredenburg 2001). IA also presents its own challenges regarding inhabitant interaction and experience that were yet to be explored in a functional IA setup. Moreover, even more importantly, the particular development state that the field of IA finds itself in must be taken into account, for it determinates which are the most important questions that presently ask for answers. This thesis studied how existing methods can be employed within the frameworks of IA, considering the specific challenges and purposes of architecture, and thus defining an appropriate approach for the field.

Given its early stage of realization, IA is surrounded by untested claims about its social relevance. On the other hand, it finds little to no demand for its incorporation into the built environment in current day scenario. Among other difficulties, IA is expensive to design, build and maintain. Thus, one of the most urgent questions that need to be answered is whether IA can in fact deliver what it claims to, assuming these claims meet real world demands in architecture and may justify the extra investment that IA represents.

This thesis discussed how interaction could potentially be an instrument to bring about inhabitant agency to architecture. This is one of the earliest rationales for the social relevance of IA. It argues that IA, through interactive feedback loops, could give inhabitants the chance to participate in the formation of the architectural spaces they occupy. This ability includes IA in the broader discussion of participatory design, inheriting its pressing real-world demand. IA allegedly defines a continuous participatory process, where changes can happen in
real time and users – not only owners, designers and other stakeholders - are the ones defining the final spatial outcome of the forms they inhabit.

To validate these types of claims, we needed first to examine processes and methodologies for testing the interaction aspect of IA concepts. As already stated, it is, after all, the interaction component that qualifies IA differently than other, better-known instances of architecture.

In IA, it is a common practice to develop prototypes of components and architectural forms. However, methods to prototype the interaction in IA have not yet been proposed and demonstrated. This work described how this could be achieved, serving as a reference for other works coming after it.

There are well-studied methodologies available in the field of interaction design that can enable researchers and designers to assess whether a system’s interaction is working and whether it is adding value to the user experience. This thesis showed how IA can take advantage of this extensive tradition. The next section of this chapter summarizes some of the most important lessons learned in the process.

This thesis also explored the necessary theories, from psychology and social sciences, needed to support the specific enquiries on human agency the proposed approach was expected to support.

Evaluation and assessment methodologies in general are known to have a particular relationship to theory that must be emphasized. They make use of well-established research theory to define the goals and standards to be employed for measurement (Deming and Swaffield, 2011). Thus, the first step of this thesis was to identify an evaluation question of interest to guide the assessment of IA instances and interaction models. The evaluation question was stated as follows: “Can interactive architecture promote inhabitant agency?” The next step was to review accepted theories in human agency and derive a measuring instrument for that concept in the context of architecture.

Based on the work of Alkire (2005) and others, this thesis described three different concepts that can be used as an indicator of human agency. These concepts are: empowerment, autonomy and capability. Autonomy and capability are part of two well-established theories, namely self-determination and self-efficacy theories, respectively. Through the last decade, these theories have generated a number of validated survey items geared towards a number of situations, which can be reliably used as measuring instruments for each concept.
An extensive literature search revealed, however, that there is no published material or readily available tools addressing human agency, empowerment, autonomy or capability in architecture.

Following express guides for constructing scales in self-efficacy theory (Bandura 2006), referencing the base theories, and using existing scales for non-architectural situations as examples, this thesis constructed a list of items that can be used in the context of architecture.

Due to time constraints, the scales proposed could not be validated during the course of the present research. This is not critical in this thesis, because its focus is on the demonstration of the process rather than on the robustness and validity of the final user data analysis. In a next stage of this study, in order to achieve valid study results, it will be necessary to test and ensure the validity and reliability of the scales used.

Particularly, following research can develop the measuring instruments presented in this thesis and provide validated scales for the concepts of empowerment, autonomy and capability with regard to the built environment. Such scales can be invaluable to user-centered approaches to architecture, especially around participatory design.

The next step in the research was to create a “microcosm” that could be used to test ideas out and to evaluate specific experiences of interest, such as that of human agency. This is the point that well-tested methods in user-centered design were employed to assist in the exploration of IA ideas and in the construction of an IA apparatus design.

This thesis presented the detailed development of an interactive space-plan concept using mixed-reality. The concept was explored using a user-centered technique for assessing user experience in early design stages. Its process was described in this thesis, including necessary adaptations for the context of IA and suggestions on how to take the most advantages of the strengths of the method. These are reviewed to further detail in the next section.

Finally, this thesis described the process of prototyping an apparatus that could be used to test the interaction component of IA, especially with an interest in assessing whether IA could promote inhabitant agency. Again, no previous work in the field has attempted similar endeavours.

The need for prototyping the interaction in the apparatus made evident the necessity of having a well-defined understanding of how this interaction can happen. To date, no interactive space-plans, built
or prototyped, exist that could serve as reference. An operational appreciation of what Interactive Architecture is, considering behaviour and interaction as main determinants in this definition, had to be distilled from speculative descriptions in the literature.

Based on these descriptions, I developed interaction models that could be implemented in an interactive space-plan setting. The development of these interaction models is another important contribution of the present work. Not because they represent desirable forms of interaction, but because they put to test ideas that authors in IA have been reproducing without systematically acknowledging other possibilities or the specific implications of the type of IA behaviour they (implicitly or explicitly) present. Thus, the interaction models suggested allow us to start to think critically about how IA is usually depicted in the literature, and provides a basis for the exploration of more thoughtful forms of interaction.

In conclusion, the goal of this thesis was to test and demonstrate a user centered approach for evaluating interaction in IA design concepts, especially with regard to the possibility of fulfilling one of IA’s many untested claims. This goal was accomplished, making explicit the problems and opportunities in the process.

11.2 Lessons learned

The main part of this thesis is the one that describes the use of user-centered design and research methods to the problem of Interactive Architecture (IA). It involved trying these methods, overcoming difficulties and learning from the process. This section summarizes the work, and highlights the most important lessons learned.

Within a range of alternatives, two interaction design methodologies were selected to explore and assess the concept: an anticipated experience diary study and a user experience study of an interaction prototype.

The anticipated experience diary study is based on a methodology for assessing user experience at early stages of product development, as proposed by Sproll and colleagues (2010). It is intended to provide insights on a product concept, especially regarding the identification of user needs, before the product is fully developed.
A literature survey revealed that available methodologies and applications for anticipated user experience studies are still limited, even beyond the realm of architecture. Thus, one of the contributions of this thesis lies on applying this type of study to a new problem, reporting on the qualities, limitations and necessity for adaptation that arose during the process.

The prototype user study, on the other hand, is a very common research design in HCI and interaction design. It was focused on prototyping the interaction rather than an artifact and, by disposing of a set of established methods, it could test people’s experience of different interaction models.

The diary study and the prototype user study are intended for different stages in the concept's development process. The diary study was, thus, the first one to be conducted in this thesis’ process, focusing on the early design concept.

One of the strengths of the diary study lies in its ability to bring up situations outside the realm of what was known or expected for a given product concept. Thus, as it was observed during this research, much of the value of this kind of study can be lost when data is aggregated for analysis.

The methodology presented by Sproll et al. (2010) gives great weight to aggregated data analysis (though diagrams, tabulations and quantitative analysis), overseeing a qualitative appreciation of what has been reported by the study participants. I found this type of analyses to provide important information as well. However, it must be complemented with qualitative, case-by-case based learning. This is especially true in the context of the present research, which did not have access to a large and representative sample of participants.

One of the main outcomes of the aggregated analyses was an overall information on how the experiences reported by participants diverged from the core concept\textsuperscript{32} (i.e., the concept as is, with no alterations). Reports diverged further when the architectural program was a private program, usually occupied by only one person at a time (e.g., bathroom and kitchen). Meanwhile, reports diverged considerably less in shared spaces. This means that, in the real world, the core concept could be useful in common areas, but not as useful in private spaces.

The core concept, which affords the re-definition of space-plan in terms of spatiality, is mostly

\textsuperscript{32} The core concept described interactive internal partitions in a space plan. Participants were asked to imagine solid walls ceased to exist, being replaced by virtual walls that could be transformed indefinitely, as need arises. The core concept also allowed control of lighting, color and temperature inside the interactive space plan.
reported in architectural programs where people need to negotiate space with each other (e.g. open offices, pubs, libraries). A review of individual reports complemented that information, indicating that the core concept was often used as a form of demarking territorialities or of communicating something to peers. In both cases, a highly social endeavour.

A review of individual reports also indicated that in non-social situations, space in terms of territory is not as relevant. Instead, needs turn more pragmatic, as in assisting people in conducting specific tasks.

It is reasonable to say that the political aspect of architecture, the one that has been the focus of this thesis, becomes evident primarily when social dynamics are salient. In other situations, IA appears to approximate much more the role of a tool, perhaps then sharing more similarities with other types of interactive systems and devices (e.g. automobile).

Another informative outcome of aggregate data analyses refers to whether participants reported some sort of automation or system intelligence when writing about their imagined experiences. Only 16 reports out of 66 did. In general, people would imagine to engage with the system when they knew exactly what kind of change they wanted made in that specific moment in time. They needed the interactive “muscle”, not the interactive “brain”.

Beyond what was proposed by Sproll et al. (2010), this thesis also probed the data, in a case-by-case basis, searching for case-specific information. A first iteration tried to identify anomalies. However, the data was very heterogeneous, making it unfeasible to identify outliers. Every diary entry could be an outlier in its own account. A second iteration parsed for not suggested or anticipated situations that, nonetheless, used features bounded by the core concept. This provided interesting insights for more sophisticated versions of the prototype, which, as built, focused only of the basic defining features of the design concept.

One of the downsides of the diary study, which was questioned by independent reviewers of this thesis, is the fact that participants are necessarily suggested by the way the concept is presented. If people had access to the system itself, this would allow them to develop a mental model of it through experience. Otherwise, participants must form a mental model based on the descriptions and images provided during the study. Although this cannot be avoided, it must be considered when interpreting the results. For instance, in the diary study presented in this thesis, it is possible that the great
prevalence of reports relating to office spaces could have been a consequence of the fact that the image used to illustrate the concept depicted an office building.

The second study presented in this thesis was the prototype user study. This study is more robust, for allowing people the experience of a prototype in later stages of development. It is, however, less open ended than the diary study and is not suitable for an early exploratory stage of a concept. I.e., it would not allow situations to emerge that are not afforded by, first, the core concept and, later, by the implemented system definitions.

The prototype user study is intended to explore the evaluation question (defined as that study’s research question). The diary study would not allow for an accurate evaluation of a specific experience component. In this second study, however, the interactive space-plan interaction models could be prototyped and participants could be subject to the actual experience of interaction.

The prototype user study was informed by the results of the diary study. Most centrally, it used the information that interactive space-plans are more pertinent to architectural programs that are shared and social. This is even more relevant when considering this thesis’ interest with inhabitant agency and the political nature of space formation.

One of the main research design decisions faced in this study related to either conducting a highly structured within subjects study or a non-structured between subjects study. A consideration of the two designs is presented in section 10.4.

Conducting the prototype user study with a non-structured between subjects design revealed two major problems. The first one was the fact that I could not get a very large number of participants in the time I had available. The second one regarded the fact that, despite the intention to provide a natural use environment, the main purpose of most participants was still to be a research participant rather than to occupy the space provided. Thus, the goal of studying natural situations of use could not be achieved. Instead, the study could only probe people’s initial experiences with the concept of IA. Solutions for these problems, however, are very possible.

In the next stages of this research, it is advised that a structured within subjects is conducted prior to the between subjects one. That research design would allow researchers to acquire more valuable qualitative data in order to further our understanding of the research problem. Information regarding the subjective comparison of the different models of interaction would simply not be accessible in
the alternative research design. In this case, quantitative data do not represent a main part of results; instead, it should focus on qualitative insight.

However, it is my conviction that after validated measurement instruments for human agency in architecture are ready, and after more qualitative insights on the problem are available, a better version of the between subjects design would be the one more suitable for providing empirical evidence against the claim that IA can promote human agency. This new version of the between subjects design must learn from the problems found in the study presented in this thesis.

The ideal setup for the non-structured between subjects study must be located in laces with known demands for the kind of programs supported. For instance, at UBC campus, the prototype could have been installed in one of the main libraries, adjacent to study and lounge areas. These areas have very high demand and often cannot absorb all of it, creating, thus, immediate demand for the new space.

The ideal setup for the non-structured between subjects study also must be a longitudinal one. It must allow participants a reasonable time of getting familiar with the space and its behaviour. IA is still a very new concept for lay users, and the feeling of novelty is overwhelming in the experience. This feeling must be overcome before significant results are generated.

The ideal setup will be able to use the already demonstrated techniques of interaction prototyping, low fidelity representation and wizard of oz. These techniques, common in HCI and interaction design fields, could be successfully employed to the study of IA as reported in this thesis.

The results of the prototype user study presented show a template for how to analyse the type of data acquired. It can serve as a reference for the next iteration of the study.

The data itself, given the problems already described, could not conclusively indicate whether IA could promote inhabitant agency. However, some of its outcomes seem to point towards interesting areas to be explored. For instance, the importance of the social role of IA when it is conceived as an intelligent space that communicates with inhabitants via natural language. The results suggested the possibility that people are more nervous when they need to communicate with the space in this manner. A full range of explorations is possible around the topic. Another example is the performance of the emergent behaviour model in several of the measured indicators. It raised the question of whether it is possible that, because of its entertaining quality, it had a positive effect on conceptually different components of interaction. This resonates with contemporary debates in interaction design.
and brings up another area of exploration for IA.

Some insights also resulted from observation during the prototype user study. They are:

- The dynamics of use and interaction diverged when participants used the space 1) alone, 2) with friends, 3) or at the same time as other participants with whom they were not familiar. The concepts of collective agency versus individual agency, which were not explored in this thesis, presented itself as a relevant way forward.

- Some comments from participants related to the antithesis of “being taken care of” versus “being in control”. This antithesis was an important stating point of the discussion presented in this thesis, however it did not take an explicit part in its final format. This is another topic that could be revisited in future debates.

- As already stated, the aspect of novelty played a huge role during the study. People spent most of their time in the space playing with the interactive space plan features for its own sake. This is an important dynamics as well, but it is just pertinent to an initial stage of a concept’s life. It is necessary to understand the role of these spaces over time.

Together, the studies presented are examples of kinds of experiments that can be performed in IA, which have been therein tested and demonstrated. In this thesis, however, they illustrate pilot studies, setting up the basis for this kind of (currently deficient) exploration in the field of IA.

11.3 Future research

The next step in this research will be to refine the research design, as prescribed in previous sections, and run a methodologically robust study to generate valid data and attest to the plausibility of IA's inhabitant agency claim.

In an even further step, this research will also revisit the models of interaction themselves and go beyond what is currently described in the literature. Aspects to consider include the integration of IA in the larger ecology of interactive devices, and the possibility to support different forms of interaction in an integrated model.
As discussed before, what might be considered the ideal forms, mediums and channels of interaction may vary according to personal and contextual circumstances. With an interest in inhabitant agency, it can be argued that IA should support different types of interaction, and even different levels of complexity within each type.

Following the trajectory, and informed by what might be accomplished at each stage of this research, in future it might be possible to design a specific instance of IA that optimizes inhabitant agency, and which can be recommended to full development and construction.


Zhang, T., & Brügge, B. (2004, August). Empowering the user to build smart home applications. In *ICOST 2004 International Conference on Smart Home and Health Telematics*. 
Appendices

Appendix A: Diary entry protocol

Anticipated user experience diary

Identification
If submitting multiple entries together, you only need to fill this box in the first page
Name: ____________________________
e-mail: ____________________________

Day: ___/___/____   Aprox. time: ___:___

DD   MM   YY   0-24h

Situation when thought of concept system occurred: ____________________________
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

Opportunity or problem identified: ____________________________
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________

Describe the experience imagined: ____________________________
_________________________________________________________________________
_________________________________________________________________________
_________________________________________________________________________
Appendix B: Final diary survey protocol

Introduction

The survey will allow us to know more about your experience with the Anticipated User Experience Diaries study and about specific diary entries you may have made.

Sections

A: Understanding of the concept

1. Was the concept of this new kind of technology easy to grasp?
2. Can you describe the concept in a few words, as you understand it?

B: The diary keeping

3. Did ideas occur naturally to you during your routine or did you have to put in some effort in order to produce diary entries?

C: Assessment of usefulness

4. In general, would you say that you would like the experiences imagined to be real? Would you want to be able to change your environment in real time for it to adapt to specific situations?
5. Does this possibility of easily changing your built environment raise any concerns in you?
6. Which of the features of the built environment you thought to be the most important ones for you to change at will? E.g. lighting, visual barriers, textures, furniture, walls, etc.
7. If you could change all the features of the built environment at will, but only inside a single room, which room would this be?
8. Which of the diary entries you made is your preferred one? Why?
9. Would you install a system in your home and/or in your workspace that allows you to change different features of the space in real time, but that is heavily dependent on electronic systems, information technologies and electric energy?
Appendix C: Initial questionnaire for the Interactive Room study

Please answer the questions below about yourself.

**Question 1**
Please select your gender: ( ) male, ( ) female, ( ) other

**Question 2**
Please write your age in years:

**Question 3**
Please use the scale to indicate your level of agreement to the following statement: “It is important to me that I have a say in how my environment should be like”.
[Likert scale]

**Question 4**
Please use the scale to indicate your level of agreement to the following statement: “I prefer choosing and customizing my own room than having a computer objectively selecting the best setting for me”.
[Likert scale]

**Question 5**
Please use the scale to indicate your level of agreement to the following statement: “I prefer choosing and customizing my own room than having another person (e.g. an architect) selecting the best setting for me”.
[Likert scale]

**Question 6**
Please use the scale to indicate your level of agreement to the following statement: “I prefer doing things on my own than relying on assistance from others”.
[Likert scale]
Appendix D: User experience questionnaire for the Interactive Room study

Introductory information
Access code: __ __ __ __ - __ (You received an access code after signing the consent form online)
Estimate of time spent inside the Interactive Room: _______ hours and _______ minutes.
During this time, how often do you think you tried to interact with the room? _________ times.
What was your main purpose when interacting with the room?

User Experience Questions
1. Please use the scale to indicate your level of agreement to the following statements about your experience with the interactive room.

<table>
<thead>
<tr>
<th>Statements</th>
<th>Scale (select only one per statement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I felt that I could influence the Interactive Room with my presence or my actions”.</td>
<td>Strongly disagree</td>
</tr>
<tr>
<td>“I caused changes to the space in the room because these changes interested me”.</td>
<td></td>
</tr>
<tr>
<td>“I feel I have control over my environment in this room”.</td>
<td></td>
</tr>
<tr>
<td>“I can have the space personalized in a way that is meaningful to me”.</td>
<td></td>
</tr>
<tr>
<td>“It was easy to use and interact with the Interactive Room”.</td>
<td></td>
</tr>
<tr>
<td>“By the time I left the Interactive Room, I believe it reflected who I am to some extent”.</td>
<td></td>
</tr>
<tr>
<td>“I feel some level of attachment to this space after using it”.</td>
<td></td>
</tr>
</tbody>
</table>
"I am happy to take credit for the current state of the Interactive Room. I helped creating it".

"I have a feeling that the spaces that came into being because of me inside the Interactive Room are mine. They belong to me".

"I interacted with the space spontaneously and automatically without having to think".

"I expected more from the experience".

"I expected the experience to be more engaging".

"I expected the aesthetic experience to be better".

"The experience was enjoyable".

"The experience made me feel competent"

"The experience made me feel powerful"

"The experience made me feel nervous"

"The experience made me feel annoyed"

"The experience made me feel bored"

"I was completely focused on my personal activity inside the room, not paying much attention to the environment or the room".
“I felt that inside the Interactive Room the way time passed seemed to be different from normal”.

2. Can you think of any needs that arose during your use of the space which were met by the Interactive Room?

_____________________________________________________________________________________

_____________________________________________________________________________________

3. Can you think of any needs that arose during your use of the space and that the room failed to support?

_____________________________________________________________________________________

_____________________________________________________________________________________

4. Would you recommend a friend to visit the Interactive Room?

☐ Yes  ☐ No

5. Is there anything else you would like to comment about your experience?

_____________________________________________________________________________________

_____________________________________________________________________________________


Appendix E: Observation notes protocol for the Interactive Room study

Observation notes protocol

Participant (attribute a pseudo name):

Interaction number:

Purpose of interaction:

Feature actioned:

Length of interaction: