Towards Adaptive Evolutionary Architecture

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Abstract. This paper presents first results from an interdisciplinary project, in which the fields of architecture, philosophy and artificial life are combined to explore possible futures of architecture. Through an interactive evolutionary installation, called *EvoCurtain*, we investigate aspects of how living in the future could occur, if built spaces could evolve and adapt alongside inhabitants. As such, present study explores the interdisciplinary possibilities in utilizing computational power to co-create with users and generate designs based on human input. We argue that this could lead to the development of designs tailored to the individual preferences of inhabitants, changing the roles of architects and designers entirely. *Architecture-as-it-could-be* is a philosophical approach conducted through artistic methods to anticipate the technological futures of human-centered development within architecture.

Keywords: Evolutionary Computation, Interactive Evolution, Architecture, Artificial Life

1 Introduction

With inspiration in artificial life *'as-it-could-be'* [1, 2] present paper seek a synthesis that extends exploration and research into the domain of architecture *'as-it-could-be'*. The ability to create unexpected situations and the opportunity to be rooted in biological, life-like occurrences is a key ingredient in our artistic and phenomenological approach to investigating the relationship between humans and future built space. The paper concerns itself with artificial evolution as a parametric design tool for architects and its use is investigated by way of a performative method conducted through an installation in a real life living lab; the results are analyzed by way of phenomenology.

Our approach revolves around the installation *EvoCurtain* (Figure 1), which explores the use of *interactive evolutionary computation* (IEC; [3]) as user-driven processes for configuring architectural elements. The installation is meant to be a showcase of how IEC could aid in designing and evolving architecture along with occupants from parameters defined by architects and designers. The goal of this research is to examine co-evolutionary possibilities between humans and technology in the context of built space. We investigate the ability to share autonomy with something technological and study what impact evolving spatial qualities has on the human experience of inhabiting a particular space.

Fig. 1. EvoCurtain Installation. The visual patterns projected onto the curtains is able to adapt to the preferences of the inhabitant through interactive evolution.

Computational technologies are already being used as tools for creating designs and calculating structures within the field of architecture [4–6]. New materials, construction methods and design directions have arisen from the impact of computers and technology. However, with our installation we are more interested in exploring the possibility for computers to work together with or assist users in creating designs for their individual preference. For the architectural practice, the challenge with the future use of computer-aided design arises when it is required to achieve a more dynamic and site-specific outcome, as the computational design-tools currently operate with a high degree of automation.

When architects are expected to design parameters rather than final designs they are placed in a completely new role. This new role demands the creation of works driven by dynamic potential instead of the traditional design knowledge. In relation, Galanter [7] mentions Whitelaw's notion of "metacreation" that puts the artist in charge of designing the initial process, which is later left to fulfill its own inherent prospective. Combined with the interactive aspect of IEC, we suggest that the key to attaining future living conditions with great individual appeal lies in the ability to design a potential, which enables inhabitants to relate to the space they inhabit in a new way.

A new branch of architecture that is specifically invested in interactive, evolving and site-specific buildings is *adaptive architecture* [8, 9]. The field is concerned with buildings that are designed to adapt to input from its surroundings; examples range from art installations to zero energy houses [10], where input can come from the inhabitants, environmental data or other key areas. Common to all projects is the notion of buildings and spaces as being flexible, interactive,

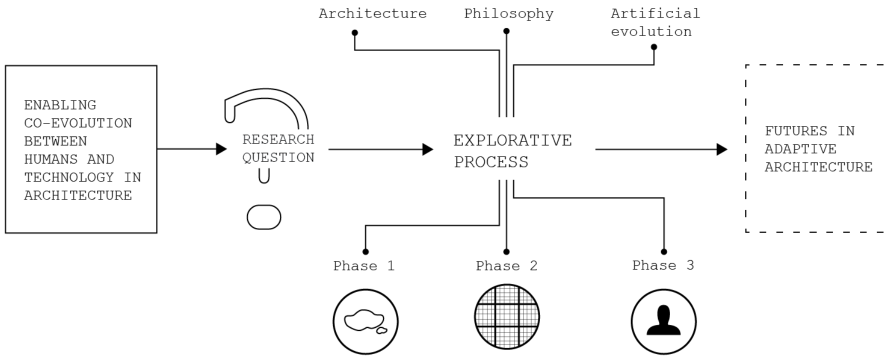

Fig. 2. Project Overview. Knowledge and experiments are generated by means of a process that progresses through the three cyclical phases of Growth Plan [11]. In order to attain an explorative study of the possible future of architecture, the research was not approached from an initial hypothesis, but rather evolved from an initial research question. In order to analyse the growth through these phases, a framework and vocabulary that enables an interpretation of human experiences is attained through phenomenology, which in turn is situated in a context of architecture and artificial life in order to contribute to the interdisciplinary field of adaptive architecture.

dynamic or responsive, which is where the field of *artificial life* (alife) becomes an apt supplement.

Our artistic exploration of desired phenomena shares kinship with approaches within alife, as it is conducted by (artificial) stagings of various phenomena – in our case, the phenomenon of humans sharing a living space with an evolutionary algorithm. From an interdisciplinary perspective, we argue that the particular fields involved in our investigation can benefit from a greater mutual involvement in future research.

1.1 Research design & Goal

The investigations in this paper are part of a larger interdisciplinary research project concerning adaptive architecture, wherein an approach known as *the growth plan* was employed. The growth plan is a method for innovative development of technology, which consists of three cyclical phases of exploration [11, 12]. We appropriate this approach in three phases: (1) An initial exploration phase, (2) a lab prototyping phase, and (3) a real life evaluation phase.

In the final phase, which this paper focuses on, the adaptive capabilities and temporal aspects of alife become an integral part of research and implementation in a real life setting. As seen in Figure 2, we sought to encompass the complexity of real life by combining alife with disciplines pertaining to built space and human experience. The challenge of investigating and enabling co-existence and mutuality between humans and adaptive technologies is approached as socio-technical.

The possible applications and experiences of our installation are evaluated with experiential performance methods [13]. The aim of combining the various complementary disciplines in an explorative process is for meaning to emerge in the context-specific interaction between EvoCurtain and its participants. To examine co-evolutionary possibilities between humans and technology in the context of built space, it is imperative to employ a tool that can aid in investigating the inhabitants' experience of engaging in a reciprocal relationship with the habitat itself.

It is furthermore important to note that the goal of EvoCurtain is not the generation of new designs, but rather to be able to longitudinally evaluate the impact and experience of the installation in a real life setting. This enables us to investigate the transformational and behavioral effects on humans in a holistic setting. And although the goal is not to develop new designs, such an approach creates opportunities to evaluate the potential of this interdisciplinary combination with regards to future approaches.

2 Background

This section reviews relevant methodologies that the approach presented in this paper builds upon.

2.1 Interdisciplinary Scope: Philosophy, Architecture and ALife

In order to understand and analyse the experiences with EvoCurtain, we looked to phenomenology - the interpretive study of human experience. Simply put, the phenomena and issues pertaining to future adaptive architecture are not readily available to our experience and investigation. Human experience can be amplified by way of technical installations, and as we seek to understand experiences mediated by technology not yet existing, this approach aids in altering experience by way of challenging life in various environments. In this context, Merleau-Ponty's phenomenology of embodiment [14] serves great purpose as its dealing with human experience of space comes by way of accounting for subjective or first-person experiences, where the body and user is at the center.

Merleau-Ponty's approach of combining subjective experience with methods more focused on empirical data strikes a balance between observation and participation in the installation. The alife approach of life-like algorithms and organic environments is fitting, as the understanding of built spaces that evolve over time needs to be externalized in order to enable analysis and design potentials. Just as phenomenology, alife attempts to capture and understand various phenomena by way of hypothetical examples and situations [15].

Having the aid of computational power aligns with the imaginative approach of phenomenology, as one approach takes root in subjective experience, while the other employs simulations - thereby being interrelating and complementary approaches. And when entering areas of future studies, where various data and experiences are not readily available for research, the conceptual approach of architecture as-it-could-be becomes a useful tool -– not just in a philosophical sense as a technological extension of subjectivity, but as an explorative tool for designing potential interactions with built space.

In the presented installation, alife gives our living room presence and agency, enabling us to engage in the complexity of real life situations that could occur when living alongside an evolving curtain.

2.2 Interactive Evolution

Participants in the presented study can change curtain designs through IEC [3], which uses human feedback to evaluate content. In IEC, human users make aesthetic decisions by rating individual candidates, thereby deciding which individuals breed and which ones die instead of relying on fitness functions designed by developers (Figure 3). IEC has been applied to several domains such as music and sounds [16–19], images [20], and visuals for video games [21–24]. While IEC has shown promise in a variety of domains, it has not yet been applied in the conventional forefront of architectural design.

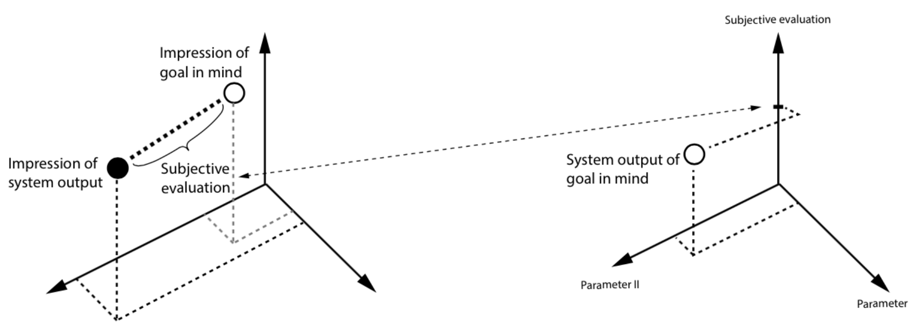

Fig. 3. Interactive Evolution. This figure shows a simplified version of Takagi's model [3]. The goal in mind of the user is situated together with the impression of the system output. The difference between impression and goal in mind form the subjective evaluation of the user, which then becomes the third parameter that the program adjusts after, forming its candidates for next evaluation.

3 EvoCurtain: The Evolutionary Window Curtain

The installation EvoCurtain explores the use of interactive evolution as user-driven processes for configuring architectural elements. The installation is meant to be a showcase of how IEC can aid in designing and evolving architecture along with occupants from parameters defined by architects and designers. To explore architecture-as-it-could-be through an IEC approach, the artifact needs

Fig. 4. EvoCurtain. Similarly to a membrane or curtain, EvoCurtain allows users to filter the view to the image of the outside world.

to integrate with the apartment and be perceived as a natural extension of existing features in the home - features that would then adapt to the inhabitants preferences over time.

Additionally, the presented project aims to merge important capabilities of humans, houses and computational technologies: The human ability to relate and sense the world through their body and perceive it subjectively, the ability of the house to provide not only protection and shelter, but also mental space for defining quality of life, and finally the ability of technology to connect, gather, compute and transform data, connecting the human as well as the house to their surrounding environment.

This notion resulted in a decision of letting the computer subject the inhabitant to images from the surrounding city in which the apartment was situated. These images are projected onto white, curtain-like pieces of hanging fabric and are covered by a pattern of white dots (Figure 4). The pattern is generated by IEC and functions as a membrane or curtain, filtering the view to the image of the outside world.

3.1 Set-up and Spatial Layout

The experiment is set up among all the existing furniture in the living room of the apartment (Figure 5). Two fabric walls are installed, which consist of floor-to-ceiling poles with white curtains. Two computers connected to two projectors display the image on the fabric walls, turning them into a resemblance of windows.

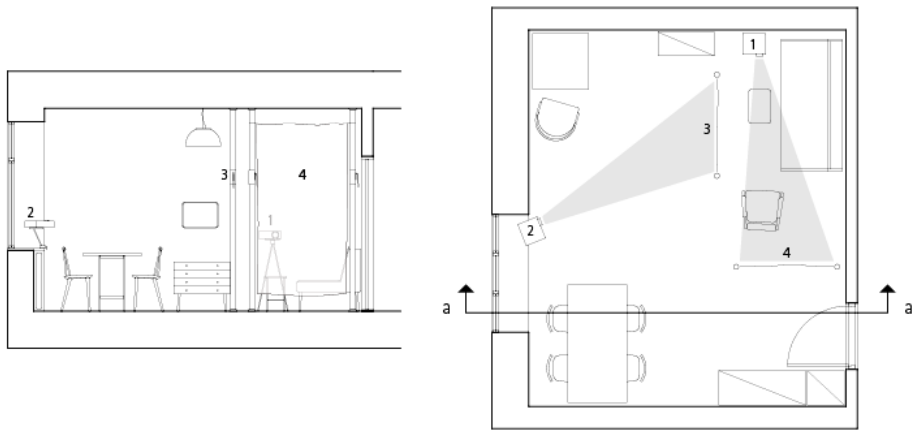

Fig. 5. Section a-a and plan of living room showing the projections of EvoCurtain and placement of wall screens.

3.2 Genetic Representation

It is important that the curtain allows the inhabitants to see more or less of the background image depending on their preferences. Five parameters are able to evolve through IEC: the minimum size of the ellipses, the maximum size of the ellipses, the speed with which they go from min to max, the amount of ellipses in total and finally their distribution over the area of the curtain. The color and transparency of the dots remains static. The ellipses are able to increase and decrease their size with varying speed and with the influence of a randomization function they appear to flutter, similarly to a curtain that waves in the wind.

These parameters form a way for the curtain to intervene by acting like a changing membrane between the inhabitant and the image. The variable ranges were tweaked and experimented with in order to create a design that would both be able to contain enough variation for the inhabitant to evaluate, but that would also resemble a natural looking element in the apartment, like a curtain.

3.3 Interactive Evolutionary Setup

The algorithm that generates EvoCurtain is an example of IEC designed to have a significant impact on its surroundings. When the algorithm initializes, it generates a population of five members. One member is shown at a time, allowing the inhabitant to rate it between zero and nine. The algorithm generates five curtains per day, and each curtain should have at least two to three hours to be experienced, before moving on to the next. When the present member is evaluated, the next member in line is shown. The members of the population thus get assigned fitness depending on the rating given by the inhabitant.

Based on the evaluation of the five members, the algorithm assigns fitness scores that decide how much chance each one has of becoming one of the parents for the next generation. The genetic properties of the two chosen parents are then combined and mutated to create the next generation of five members, to be evaluated in the following session.

4 Experiments

The experiment was conducted over the course of ten days, where an interventional installation was set up in an apartment – home to one of the authors. The experiment included ourselves (two of the authors) as well as four additional test participants through an experiential method. The method used in the experiment was conducted by way of three different sessions, exploring the space in both a personal and social way.

Following the *triangulation method* [13], We performed three different sessions, each represented a different angle on the space that we were exploring (Figure 6). The first session, which continued throughout the whole experiment, consisted of ourselves experiencing the room through living with it for ten days, noting down our own first-person experiences. The second was 20 minute interviews where we each took turn to question each other and get questioned in focused two-person sessions. The third session was a structured performative

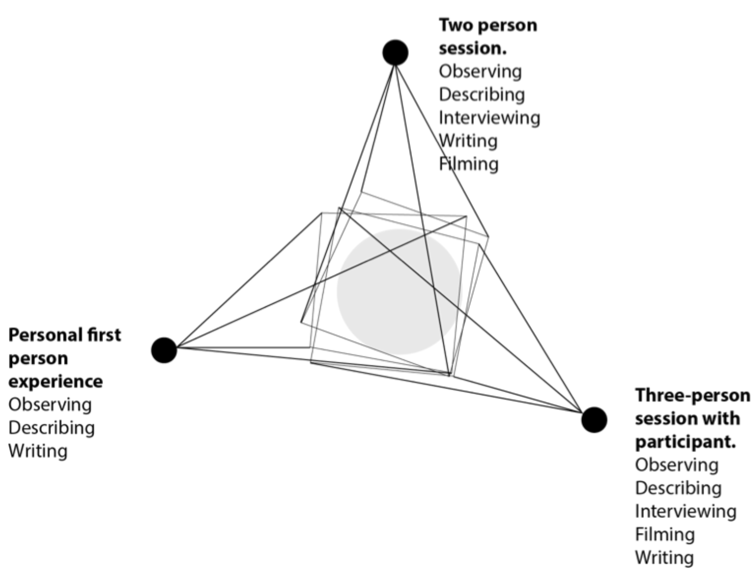

Fig. 6. Observational structure. The experiment is observed through three different angles.

three-person session, where we invited test-participants from the first phase and assigned each a role of instructor, observer and experiencer - assuming the same triangular set of observation positions as in our second phase of experimentation. An important supplement to the method was that the experiencer was equipped with a camera in order to record their 1st person-perspective. This was done with test-participants as well as when we questioned each other.

The video from all perspectives would afterwards be re-watched and interpreted by us. We had furthermore added an extra criterion in our questioning: When continuously asking the participants about their relation to the room, the relation was to be accompanied by an evaluation, which was then plotted into the evolving algorithm. This was to create a recurrence of relation that brought not only the co-evolving engagement to the forefront, but also the question of who was in control.

Outside of the staged methods various scheduled activities such as lunch with guests and other 'everyday' activities were added in order to give depth to the first-person experience for the one of us was living in the space.

4.1 Genetic Experimental Parameters

Each of the five genes describing the evolving curtain had a 25% chance to mutate every time a new generation is created. The minimum size of the ellipses was set between 0 and 70 pixels. The maximum size was set between the minimum and 70 pixels. The number of ellipses could vary between 100 and 1000 and the position of each ellipse was generated by a perlin noise function. The speed of the ellipses was scaled between zero and one, where zero is a complete standstill and a setting of one means pulsating between the max and min size once per second. The parameter ranges were tweaked and experimented with in order to create a design that would both be able to contain sufficient variation for the inhabitant to evaluate, but that would also resemble a natural looking element in the apartment, like a curtain.

5 Results

The algorithm aided in providing a sincere experience of living with something that had intelligence and agency - a computer program manifested as a visual prototype, which was capable of reacting on its own and interpreting inputs. The fact that the algorithm were convincing became evident when one of our participants referred to it as something she could have discussions with and afterwards commentated on its changing behavior by saying *"Oh so you think you know what I want, huh?"* Participants furthermore wondered how this relation would be if living together with another human and the algorithm. Their thoughts on this was that the algorithm would act as a kind of conciliator between the human inhabitants in that the participant imagined that they would have to all adapt to each other to co-exist.

Test participants provided a necessary perspective on our own experiences, as the need of assuming several observational positions gave us additional insight into how a living situation with multiple agents with agency could occur and thereby qualified our own role in the experiment.

Figure 7 shows an example of the progression of the interactive evolution guided by a test participant. Evolution takes place when genes of members from current generations mix and form the future generations of patterns. The change thus unfolds without inhabitants noticing and only when the representation emerges for them to experience and evaluate, do they see the result of the evolutionary process. The fact that anything is changing is sometimes not even visible at first; only after a few generations do the test participants discover the change. The mixing of genes, combined with mutation, evolve into more and more similar patterns based on the evaluation of the human. It must be noted here that the patterns were not static in nature and thus still images do not do it favor. A video of EvoCurtain in action can be found here: https://goo.gl/d8ITBz.

5.1 Disagreement and reconciliation

Following the first stages of the experiment, the algorithm reached a point where it appeared 'stubborn' – it kept showing similar patterns during the span of five generations regardless of the chosen patterns. This was observed as the inhabitants and the algorithm 'disagreeing' on the spatial qualities of the room.

As time went by, test participants started to have less focus on the patterns as a purely visual feature and started experiencing it as a metaphor of something living. This marked a certain shift in the way the room was engaged and the knowledge that became embodied in that relation helped re-open the space to interpretation. The use of IEC over a longer period of time meant that we were allowed to study evolving relationships between humans and built space, which changed and achieved a certain rhythm as it became more integrated in everyday activities. It was no longer a question of controlling EvoCurtain, rather, the attitude of participants tended towards allowing oneself to co-evolve with it. The advantage of having the prototype develop in a longitudinal study thus became clear, as the experiences of who was in control drastically changed. This had not occurred in earlier experiments, where prototypes were only engaged for a maximum of four hours.

5.2 Control and preconceptions

Despite initial concerns about the experience of relinquishing control of one's intimate space to something non-human, it ceased to present itself as a major challenge. Our interpretation of what the participants had experienced in earlier non-alife experiments was that their lack of control made them uncomfortable; they regarded the prototypes as potentially non-cooperative.

We argue that the issue for the participants in the second phase was that they had to come to terms with the technology as an 'other', to use Ihde's terms [25], and realise that how they moved and interacted was a 'dialogue' - a relationship that needed time to develop. It was realized that an important thing to consider is the preconceptions humans have about technology: We are used to

Fig. 7. An example of ten generations with five members each that were rated by a test participant.

controllable and carefully designed interaction. Having to live with technology that in unfinished in the beginning, but develops over time is a new relation that humans will most likely need to adapt to in the future. A simplified but current example of such relation is the iPhone's Touch ID, which improves its ability to recognize the user's fingerprint over time. The fact that the identification does not work perfectly at first but after a few days functions seamlessly, might represent an anticipation of such a phenomena. In the future, technology might develop alongside humans instead of coming out of the box with a finished design, as the advantages of letting it develop and adjust to individuals is much greater than that of uniform designs.

5.3 Time

The temporal aspect was an underlying theme for the entirety of our project. The perceived changes in the relation to EvoCurtain meant that the participants' experience of inhabiting an adaptive space felt more akin to being *with* the room, rather than merely in it. During the longer period of testing with EvoCurtain, it was observed how the room slowly ceased to be regarded as an object and was instead experienced as something dynamic and living. We thereby believe it is possible to argue for the inherent quality in developing future living environments, if approached as an entity that adapts its design qualities through an evolving relationship with the inhabitant based on individual preferences, as opposed to a building with customizable smart technology.

5.4 Interdisciplinary perspective

It is no trivial matter to evaluate how successful the application of IEC and alife is in an interdisciplinary project like EvoCurtain. A measurement of IEC's utility and performance is challenging to achieve in an objective manner, as the results are based on user interaction and subjective experiences. However, the fact that computer simulations helped stage some of the complex environments pertaining to adaptive architecture, not only allowed for an investigation of human experience in realistic settings, but speaks to an initial success from an interdisciplinary perspective.

As such, using artificial evolution to explore the possibilities of adaptive architecture appears to have many complementary qualities. Just as a gradual adaption over several generations can be called evolution, adaptive architecture can come to be called (interactive) evolutionary architecture. Prototypes with adaptive capabilities seem to be a necessary component when exploring the design of living technology and spaces to be inhabited in a holistic manner. Using evolutionary algorithms in explorations of how built space can be understood and designed in a meaningful way for the individual has significant implications for architecture (spatial design), arts (staging of experience) as well as philosophy (analysing the experience of the space). The initial estimate is thus that the privileged position of each field can aid in yielding tools, which meet the requirements for designing built spaces that has dynamic and adaptive interpretations of the surroundings, where both human and surrounding environments are included in the loop.

6 Discussion

Langton suggests that *"traditional biology studies life-as-we-know-it, (...) Alife seeks to explore the possibilities of life-as-it-could-be"* [26]. In this paper, we argue that alife can be used to explore architecture-as-it-could-be.

Alife explores phenomena using artificial means to expand our imagination of what is possible and IEC can create an outcome that is based on human input. Architects are concerned with the quality of living spaces, and evolutionary algorithms are concerned with fitness values. From the perspective of the inhabitant it is one and the same: The built environment that is best fit to be currently inhabited. What is important to note here, is the interim nature of the definition – the same space might be perfect in one situation and unsuitable in another. Thus neither evolution nor humans gravitate towards finalized solutions, but rather the most fit proposal in a given situation. To architects, this is a new way of looking at computation; through the eyes of nature. Evolution takes time and "problem solving" in nature is a slow process. Development of buildings in the future could be thought of as an adaptive process guided by the interplay between inhabitant and building. This means that there are no predefined goals, as the aim of adaptive architecture is to adapt to the inhabitants and the surroundings as the current preferences, needs, and conditions develop and change.

Jaskiewicz [27] considers the idea of stretching the sketching phase of a building project to continue into the actual built structure, providing the same adaptive features as the computer or architectural cardboard models: *"The architectural models developed as representations of future habitats could be developed in such a way, that their inherent logics are employed to drive the adaptive processes in actual architectural spaces"*. Through his thorough analysis of the architectural practice and the functional programming of buildings, Jaskiewicz concludes that the ability to adapt to its environments is an important success criteria for architecture: *"Architectural spaces that can be frequently transformed to match changes in the conditions of their internal and external, artificial and natural environment are bound to be more "successful" than those spaces that do not adapt to these changes"*. He further goes on to say that this criteria is something upon which buildings should be evaluated, as it relates closely to the holistic performance of buildings and therefore the success as living spaces.

What we found in our studies was that humans in turn would have to adapt themselves to the system in order to enable the interaction that constantly makes both parties better suited for each other. Adaptive architecture is as such an adaption in (1) the built structure, (2) the mind of the inhabitant and (3) the role of the architect. Considering Whitelaw's [7] notion of metacreation, the shift in the future role of architects and designers can be suggested to have much in common with the shift happening in the role of the artist: *"Metacreation refers to the role of the artist shifting from the creation of artifacts to the creation of processes that in turn create artifacts"*. In *vernacular architecture* [28] buildings change as extra rooms and new kitchens are created from existing mass, morphing out where space is available and building upwards where it is not. This notion should be kept in mind when imagining buildings that evolve based on the feedback of their users, in which only the overall process is defined by an architect. We suggest that computer technology can enable an extension of imagination, using means that aid sense, eyesight and logic, while being evaluated by humans to push exploration and development in a direction most fit for human life to unfold. Jaskiewicz [27] mentions evolution as a safe strategy for evolving adaptive buildings. He suggests that in order to solve the problem of adaptive architecture evolving into something dangerous we must look at the complex systems of biology. Here, the two main qualities are development and evolution, and over time adaptive architecture will become increasingly more secure and dependable. He also argues that a way to avoid initial challenges would be to make use of virtual scenarios for testing, before implementations in real life. This notion suggests that when inhabitants conduct the fitness evaluation it is possible to assume that no building evolves in an unwanted or harmful way. Following our investigations, we noted that the question of who is in control was relatively non-pertinent. Rather, it became imperative that inhabitants were able to perceive themselves as participants and creators rather than users, and to expect a mutual development to unfold as opposed to using a finished product. In order to enable inhabitants in actively engaging with future built spaces, one must understand how the relation to an adaptive building can be made meaningful for the individual in an everyday setting.

Through our investigations on adaptive architecture, the contribution that alife offers in an interdisciplinary setting becomes apparent. In trying to understand human experience in the context of possible future technologies, the use of alife helped create environments that introduced a sense of embodiment and engagement. It furthermore elucidated how simulations can lead to new experiments when investigating complex human experiences. EvoCurtain has obvious limitations regarding scale, time and objectivity when it comes to investigating human navigation and experience of adaptive spatial qualities. We thereby argue that in future investigations of this kind, philosophy and architecture alike can benefit from alife's ability to construct phenomena and data that can aid in the development of new designs based on more advanced understandings of human-technology relations.

Adaptive architecture thus poses a new challenge in developing interdisciplinary methodologies for designing and evaluating parameters in a holistic manner that appeal to our embodied way of being. We argue that an interdisciplinary and explorative approach akin to the small steps taken in this project is key to anticipate the futures of adaptive evolutionary architecture: architecture-as-it-could-be.

7 Conclusion

Our work presented and evaluated the implementation of IEC in the context of architecture and philosophy. This interdisciplinary approach is represented in the EvoCurtain installation and has proven a useful approach in attempting to unfold the complexities inherent to adaptive architecture. The way EvoCurtain was implemented can in itself present a novel approach to how future adaptive environments are to be investigated, where the qualities of the building adapt to the activity and behavior of its inhabitants, be it lighting, spatial qualities, thermal conditions or other conditions pertaining to the spaces we inhabit.

Due to the nature of the installation it was difficult to measure the direct impact of IEC, we have however seen indications of the relevancy of employing alife and IEC to attain aspects of the complex experiences pertaining to the inhabitation of an adaptive environment. As it became apparent how alife amplified the nature of the relationship to the built environment, it not only enabled more refined philosophical studies of how participants experienced the surroundings, it offered a way of anticipating the possibilities in future relations between inhabitants and built space.

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