Architectural Interfaces for Shared Spaces

A Multi-User Perspective on Intelligent Environment Interactions

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Abstract. Current examples of intelligent environments aim to automate certain functions in buildings to relieve humans of redundant tasks. However, not having any information about the changes in the environment leads to the feeling of being controlled. Recent developments in the human-building interaction field focus rather on human-centred designs, which offer people more control over these systems. The interfaces that are created to provide control are usually designed with one user in mind. Most of the research on Human-Computer Interaction (HCI) also focuses on the interaction between one person and one interface. However, in cases where the space is inhabited by many people, this system of control and its communication becomes more complex. Therefore, there is a need for interfaces that represent environment-related information within a shared architectural space. This argument applies to cases where multiple people would prefer to control their immediate environment, including shading, heating, and ventilation, as well as wayfinding in crowded environments, such as conferences, fairs, and concerts. Instead of distributing this information to individual cell phones, it can be embedded within architectural space, as envisioned in ubiquitous computing systems. This means that the architectural space itself becomes the interface, allowing for a more seamless and integrated interaction and offering more social and collective experiences. This paper will provide the theory and necessary literature demonstrating the need for and the potential of architectural interfaces for shared spaces. A framework for a potential system will be proposed regarding HCI and ubiquitous computing research from an architectural perspective.

Keywords: human-building interaction, architectural interfaces, intelligent environments, interactive architecture

1 Introduction

Currently, most intelligent environment (IE) projects focus on the automation of certain building functionality, such as heating, ventilating, and lighting [1]. They are often designed to provide a more sustainable and comfortable environment for the inhabitants.

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However, their parameters are predefined and cannot be changed by the users [1]. This situation usually leads people to approach smart and intelligent environments with certain scepticism since the comfort requirements of every individual differ according to age, gender, and activity type [2]. When these requirements don't match their comfort, people would rather take control of their surroundings and make the system useless [3].

Therefore, it is important to include people within this feedback loop, not only to make everyone more comfortable but also to increase the acceptance of these systems [3]. Creating communication is the most critical part of integrating people into IE systems [4]. Important factors are making interactions visible for everyone involved and explaining the impact they have on other people [5]. This paper examines architectural interfaces – spaces that communicate with their inhabitants – as a framework for investigating key themes: how to include user feedback into IE, how to evaluate their impact, and how specific use cases can exemplify these developments.

2 Intelligent Environments and Their Control

The understanding of the built environment is changing with the incorporation of intelligent systems into architectural spaces. The space, which was considered the background of daily activities, now becomes an active part of our lives by responding and adapting to our needs and even influencing them [6]. These IE systems have an impact on the experience of not only architectural space but also technology. When technology consists of objects, people are "users" who use them, but when it becomes the whole space, it becomes something that people "experience" since they inhabit it [7]. However, because this topic has not been the focus of many architects, the inclusion of these systems has been rather late in the process, making them not very intuitive. Additionally, the control mechanisms of these intelligent environments are usually hidden and inaccessible to many users, especially in shared environments. The following diagrams are developed based on insights drawn from the article about understanding the agency of interactive architecture through actor-network theory and cybernetics [6].

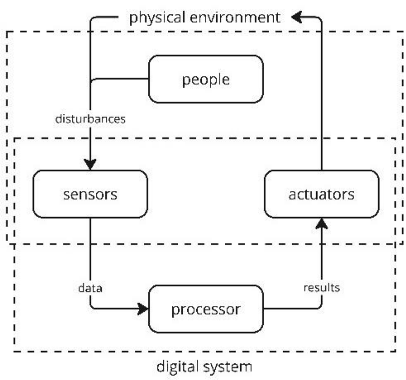

Fig. 1. Flowchart of an intelligent environment.

Figure 1 maps out the working mechanism of a typical intelligent environment that consists of physical and digital space. When people occupy a space, they have an impact on their surroundings, such as changing carbon dioxide levels by breathing or changing the room temperature with their body heat. At the same time, the weather changes outside the building, having an impact on the heat and moisture levels on the inside. Both factors create "disturbances" within the balance of the indoor space. Within IE, these changes are measured through sensors and compared with the idealised version of the environment that is predefined. In most of these spaces, people don't have access to the predefined goal and whether it matches their comfort levels. After the comparison, the system makes a decision whether it will change anything in the space. The results are processed by the actuators, and they act on the environment automatically, without any human input.

According to the study by Zhang et al., the most common factors affecting the control of the existing adaptive façade systems are weather and occupant behaviour [3]. Since the weather parameters can be easily measured with sensors, such as humidity and temperature, it is integrated into most of the projects' control. However, even though occupant behaviour has a huge impact factor on system performance, it has "not been incorporated into self-control strategies" since behavioural and social parameters "cannot be measured with typical sensors" [3]. Therefore, instead of taking personal comfort levels into account, in most intelligent environment systems, the calculations are done based on one average idealised person [8], and automated actuator systems are used. Even though they are easier to manage, they usually have lower satisfaction rates from the users due to having "poor visibility and thermal comfort" in addition to not allowing personalisation [3]. People cannot decide about the environment themselves, and they change what they can control, which leads to the same amount of energy consumption, such as turning on artificial lights during the day, because they have limited sunlight caused by automated shading systems [3].

When people don't have access to the control of the system and don't understand the system's behaviour, there is a significant decrease in "user trust, satisfaction and acceptance" [7]. Therefore, it is crucial to carefully consider the human aspects of the system. According to Bellotti and Edwards, there are four principles that can establish trust and understanding between users and the system: "informing users, providing feedback," being clear about the sharing of user data, and "providing control to user" [9]. The relatively new field, Human-Building Interaction (HBI), has a similar aim, focusing on "human values, needs, and priorities in addressing people's interactions with "smart environments" [10]. Some of the HBI theories draw parallels between humans' "perception-action loop" and the sensor-actuator mechanism of intelligent environments, which strengthens the simultaneous interaction between space and people [11]. People perceive the environment much like the sensors of the system, and they behave and act to make changes just like the actuators.

For the control of IE systems, there are some examples that already include communication interfaces, such as smartphone applications. Even though they are very efficient in presenting updated information, they provide very individual experiences [8]. Most of these examples focus on the "communication of one person with the space" [6]. In the case of shared spaces, designing individual interactions means excluding everyone except one person in the space. So, as a solution, people have to either take turns and negotiate the interactions or potentially overwrite the previous person's request [12].

Existing HCI examples are overwhelmingly dependent on mobile screens that are designed for one single user. Even if the interface is placed in a public space, such as timetables for train arrivals, people usually gather information by themselves and do not interact with other people in the area, making the interaction experience very individual. These mainstream examples of screens become more interactive when they get smaller and more personal. Media architecture, which can be described as digitally enhanced public spaces that offer interactive experiences [13], is the intersection of these two characteristics. These projects are usually located in the urban environment, such as building facades or stand-alone screens, and aim to interact with many people for communicating content, placemaking, or showcasing media art projects [14]. Their nature of being large-scale and interactive simultaneously makes them a good resource for both theoretical basis and applied examples.

Even though it is not very common, there are still examples of interfaces designed for interactions with multiple people within the architectural context. In the study by Rogers et al., they placed various interface types around the office –a screen and an installation– to encourage people to use the stairs more frequently instead of using the elevator. The screen they used was not recognised by most of the users at all, even though it was the most informative interface among others. The abstracted tangible interface grabbed a lot of attention; however, the message was not clear to the people at all [15]. This is a deeply complex balance to find, and designers of these systems should carefully define the significance of each criterion for their project according to their context.

3 Architectural Interfaces and Their Criteria

The term Architectural Interface is not an established term, but here, it describes digitally enhanced environments that communicate with their inhabitants. The Architecture before the Interface highlights the spatiality of these systems, meaning that they are embedded and distributed in the space.

Considering the areas of improvement for IE systems mentioned in the previous chapter, our suggestion is to include people in this feedback mechanism, not as another factor that creates the "disturbances," as seen in Fig. 1, but as active participants of the system. That means connecting physical and digital space via an interface that defines the communication space, as illustrated in Figure 2. The addition of an interface expands the functionality of the system by including human agency in the feedback loop. In addition to typical systems, here, people can change the goals of the system through the interface, and they can be informed about the results of the system's calculations. It means that the flow of information could happen in both directions. However, it is not necessary in every use case.

Additionally, it is important to highlight the importance of designing these systems by considering all the occupants in mind. In both directions of the flow of information, entering the preferences and getting information, it is crucial that the interfaces are designed for interacting with multiple people, since the focus is on shared spaces. To clarify, in order to improve current IE systems and make them more human-centric, there are two important steps to be taken:

1. adding an interface to the feedback loop and
2. designing this interface for multiple people.

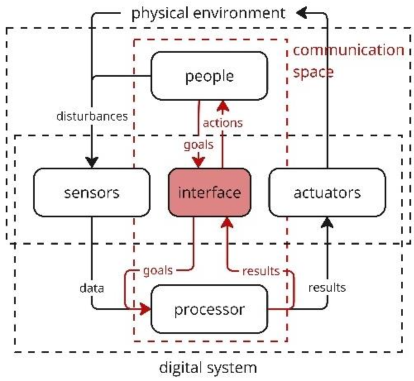

Fig. 2. Addition of interface to the system.

In order to take the aforementioned steps, we will use the framework from Wouters et al., who discussed different characteristics of public media displays through “physical, experiential, and communicative” qualities [13]. *Physical quality* relates to the relationship between digital displays and the physical characteristics of architectural space. *Experiential quality* refers to “atmosphere and responsiveness,” which focuses on collective experiences and available interactions with the digital space. *Communicative quality* highlights the content and its relation to the architectural context [13].

Regarding the *physical quality*, it would be beneficial to dive deeper into embodied interactions for the architectural interface context. Embodiment considers our bodily senses as an important part of our cognition and understanding of spaces [16]. Tangible and social computing systems aim to adopt this intuitive understanding of the environment by designing systems that integrate physical and digital spaces [17]. Rather than restricting interactions to single screens, architectural interfaces could provide diverse interaction mechanisms that include full-body movements. This concept traces its origins to the idea of ubiquitous computing, the term coined by Mark Weiser [18]. It is suggested that computers will fade into the background, seamlessly embedding technology into everyday spaces [18]. While designing architectural interfaces for shared spaces, it is even more important to utilize our intuitive understanding of space and technology by embedding and distributing these interfaces into space. Thus, the boundary between digital and physical space fades out, and the architectural space becomes the medium of interaction [17].

For the *experiential quality*, the paper by Behrens et al. dives deep into the sociospatial interaction frameworks and explains how the addition of interfaces changes not only the personal perception of the environment but also the interaction between people mediated through these interfaces [14]. These frameworks include "awareness, actor, action, and physical space" factors, each focusing on a different element within the interaction mechanism and how it affects social relationships [14]. Even though these theories are focused on urban space, they provide a useful framework for the architectural interface context as well. Finally, *communicative quality* refers to how and what kind of information is conveyed to the people. Since it is extremely context-dependent and varies greatly in different examples, it would be useful to discuss this framework in relation to concepts and project examples.

4 Flow of Information and Their Use Cases

As mentioned in Chapter 2, with the addition of interfaces, there are two possible flows of information: changing the system's goals and getting information, but it is not always necessary to focus on both in every use case. These two flows of information also indicate the balance between automation and interaction. Distributed Control systems concentrate on people's ability to control the environment according to their preferences and make compromises in shared spaces. The system is still highly automated; however, it allows more interactions with the user. Informative Guidance systems focus on communicating environment-related information to inhabitants simultaneously and informing them about necessary actions. The system is less automated and more dependent on human interactions with both the system and the environment.

In the following sections, these systems will be explained with the help of various use cases and examples. Most of these examples are conceptual projects, and they aim to demonstrate the potential of each system. Afterwards, these systems will be analysed according to the criteria mentioned in Chapter 3. The key points of the analysis can be seen in Table 1, and they will be explained in detail in each section.

Table 1. Analysis of systems and use cases based on the criteria.

System	Use case	Physical quality	Experiential quality	Communicative quality
Distributed Control (Chapter 4.1)		The distribution of: • actuator mechanisms • personal interfaces	• Control • Compromise	• Current situation • Preferences • Negotiations
Guiding Information (Chapter 4.2)	*Ambient Guide (4.2.1)*	• Position in the space • Limited attention required	• Responsibility • Control	• Changes in the environment • Possible actions
	Active Guide (4.2.2)	• Embedded in the space • Interactive	• Intuitive • Shared	• Guidance for a specific question

4.1 Distributed Control

In distributed control systems, the substantial flow of information is about people informing the system about their preferences, as seen in Figure 3. People are also informed about the current situation and the results of the system, but the distinctive quality is about control. The distributed control systems require the elements within the actuator mechanism to be controlled individually, as well as additional interfaces for individuals. This means that people don't have to adjust themselves according to the idealised person's data; hence, everyone can arrange their preferences and feel comfortable at the same time. Additionally, the system is designed to support users by facilitating a negotiation environment and mediating conflicts when necessary: automated solutions for explicit conflicts, user-guided mechanisms for addressing implicit ones, or employing spatial or temporal interventions [19].

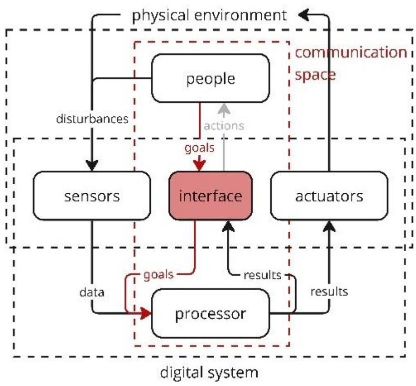

Fig. 3. Flow of information within distributed control systems.

The first example is a master's student project that was developed in our architectural design studio. By Fritz Schulz and Bénédict Bettermann, the North Sun project is an interactive mirror installation specially designed for the northern façade of the buildings facing a narrow courtyard. As seen in Figure 4, the mirrors are placed on the roof level of the courtyard to capture and reflect the sunlight in the best way. Instead of creating an automated rotation of the mirrors according to the position of the sun, a distributed system was created to allow everyone to adjust the mirrors according to their wishes.

Each mirror is assigned to a different apartment, and they can be controlled with an app. The control options are varied, including manual control to change the position of the reflection, selecting rooms to direct the light, or collaborating with neighbours, where they can all collect sunlight in the courtyard. Since each mirror is designed with a limitation that can be rotated within the limits of each apartment façade, there are not many negotiation aspects in this case. Neighbours don't have to come to an agreement because they are not affected by each other's "North Sun."

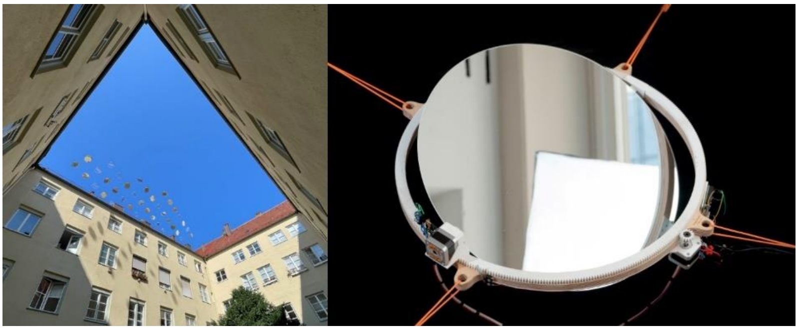

Fig. 4. North Sun project.

The second example, a conceptual project that was developed by the authors, is closer to the existing adaptive façade projects and takes place in an office setting. Figure 5 depicts an office environment with two stations and two windows. Each window has adjustable shading elements that can be adapted to have different amounts of sunlight in the room. The concept includes a system where each person can adjust their own illumination level through an interface on their stations. If each station were affected by only one window, the calculation would be easy and straightforward. Due to the rotation of the sun, there are times when one window affects both desks, as represented in Fig. 5. At this point, it is important to consider the scenario in which two individuals have differing preferences for illumination levels, while only one window serves as the sunlight source. So, the interface is not only a medium where people type in their personal preferences and get results, but it is also a medium for interpersonal negotiations. It mediates these negotiations by both showing the impacts of their preferences on others and offering potential solutions. This concept illustrates the complexity of distributed control systems with only 2 windows and 2 stations. For real-life situations with many more impacting factors, the system would incorporate these complex calculations.

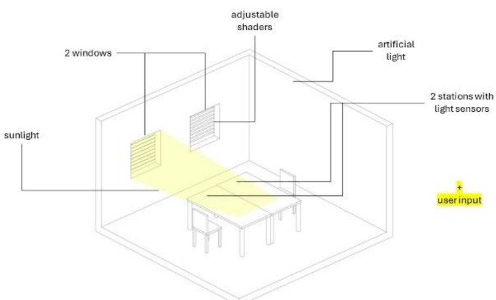

Fig. 5. Distributed control systems example in an office context.

For the *physical quality* of the distributed control, it is very crucial to consider the distribution of actuation elements and personal interfaces. For the North Sun project, the mirror actuators were placed in the courtyard, whereas for the second project, they were placed on the building façade. Additionally, the control of the first project was done by a phone app, while the interfaces were directly connected to the stations on the second. This distribution has a great impact on the functionality of the systems. For the *experiential quality*, both of these projects give people control over their own environment. And especially for the second project, the system also works as a mediator between people. For the *communicative quality*, it is important for people to be informed about the current state of the actuators, be able to type in their preferences, and see if they are affected by the same factors as other people, also discussed in Chapter 2 [9].

4.2 Informative Guidance

In informative guidance systems, the flow of information is in the opposite direction. Even though providing some feedback about the environment exists in various cases of smart environments, there are not many examples that include humans as the main actors of the whole system. Figure 6 illustrates that the results are communicated with the inhabitants through an interface, and people act as the "actuators" by changing and improving the environment. In this case, the system is less automated and relies a lot on human involvement, which makes it particularly important to improve existing buildings. By adding the necessary sensors and an interface, older buildings can also function as intelligent environments without the need for automating the whole space. In normal environments, people are motivated to make environmental changes according to "various different physiological, psychological, or sociological factors" [2]. For informative guidance systems, the interface is the main motivator for people to make the necessary changes, which makes its design very critical.

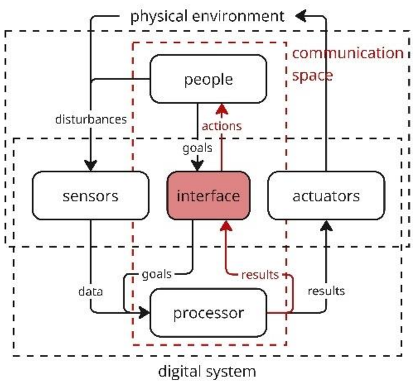

Fig. 6. Flow of information for informative guidance systems.

Building on these frameworks, two core concepts will be explained in detail, the classification of which is informed by the Tangible User Interface (TUI) research conducted by Ishii and Ullmer. They identified that in designing tangible interfaces, whether people utilise background or foreground awareness is crucial. Background awareness is associated with "ambient media," whereas foreground awareness is related to "graspable media" [20]. Therefore, the following ideas will be called ambient guide and active guide.

Ambient guide

In the ambient guide concept, the interface visualises the changes in the environment for the people inhabiting the space so they can take action before the situation becomes unbearable. This concept sees humans as one of the main actors within the intelligent environment, and as a partner that can be collaborated with [21]. The data could differ from air quality to sunlight glare, including other comfort factors within an architectural space.

The most significant advantage of this concept is that it does not require the whole space to be automated, similar to prevalent examples. Here, the addition of sensors and an appropriate interface would encourage people to take action about the changes within the environment and bring it back to their comfort zone. Additionally, since people have knowledge and take action, one of the biggest challenges against intelligent environments –the feeling of being controlled– will be reduced [7].

Zhong et al. provide an extensive study on this subject. Their focus is on improving indoor air quality by informing a group of people within an office environment through different interface types. The striking outcome is that it makes a big difference if the information is shown to everyone in the space with lighting colour changes in comparison to getting personal notifications. When it is indicated with light, and everyone knows that there is too much carbon dioxide in space, someone takes action. If they get a personal notification and think they are the only one who knows about it, they are reluctant to make a change in the space, thinking that they would disrupt the meeting [22]. This study shows that aside from the content of information, the interface type also has a big impact on how the message is understood and acted on. Especially within shared spaces, the interaction style has a big impact on interpersonal expectations about the maintenance of the space as well.

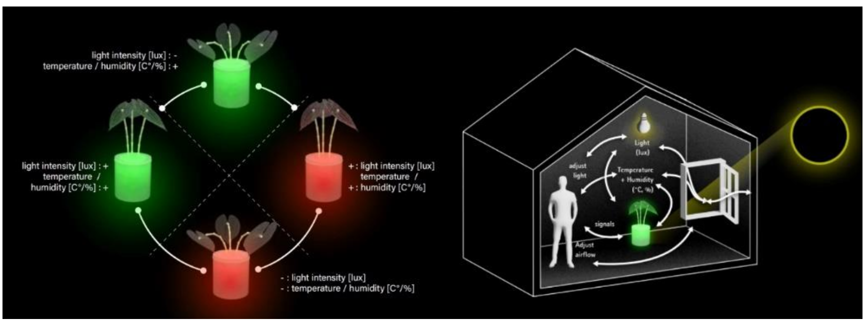

Fig. 7. Ambiplant project.

Another example is a student project that was developed in our architectural design studio. Natalie Judkowsky and Sebastian Zitzmann used the same mechanism of informing people about the oxygen and illumination levels in space. As seen in Figure 7, they designed a cybernetic plant that changes its light and leaf position to show the changes within the space. The changes would be represented via slow adjustments within the tangible plant interface. Here, people are expected to make changes according to the represented data and their current comfort. Even though their focus was on domestic space, which has relatively fewer inhabitants, it still provided an interesting interface example that could fit the description of the ambient guide.

For the *physical quality*, the placement of the interface is vital, as seen in the first example. Additionally, in both examples, the ambient nature of these interfaces allowed people to recognize changes only if they passed a certain threshold. Otherwise, these interfaces don't require much attention and inform everyone in the space simultaneously. These examples stay within the "peripheral awareness" most of the time. When a significant change occurs, people shift to "focal awareness," and at the end, one person switches to "direct interaction" and changes the environment [23]. For the *experiential quality*, people have more responsibility compared to the distributed control systems, since they become the actuators here. This responsibility promotes a stronger sense of control over their environments. When people's comfort levels differ from each other, the negotiation aspect of the environmental arrangement is more direct and confrontational than the other examples. When someone takes an action to change the environment, the action and the reasoning will be immediately visible to others. It is assumed that this will allow communication between inhabitants about their comfort levels and the needs of each other. For the *communicative quality*, it is important to visualise the changes in the environment in a clear way, e.g. light or movement, and the possible actions that can be taken.

Active guide

The active guide concept also focuses on informing people, but in this case, it describes a situation where people are actively seeking information. Wayfinding in crowded environments can be a good example in this context. Most wayfinding research is either on fixed solutions or personal navigation systems [24]. Fixed solutions include designing a building layout that allows people to easily recognize the environment or creating specific signage systems related to graphic design, such as for hospitals or airports. Personal navigation systems are generally used within urban environments, and a very limited number of examples focus on architectural spaces.

The focus of this concept is using architectural space as an interactive guide to show people where they need to go, instead of hundreds of people looking at their phones at the same time. It can be used for spaces that people rarely visit and have difficulties with wayfinding due to the crowds or confusing layouts, such as conferences, fairs, or big halls. In this context, examining specific artistic and research projects may provide valuable inspiration for advancing this concept.

The first option is to use a light projection that would transform the whole space into an interactive one. This technology has often been used in artistic installations to design interesting and interactive experiences, such as "Vanishing Point" by UVA [25] and

"Intentional Particle" by Umeda [26]. The most inspiring one for the active guide concept would be the "Wissensfeld" project by Weibel and Lölkes, which uses light projection technology as a search function [27]. Each person who enters the interaction space is highlighted with a circle, and by walking toward the keywords, they can activate encyclopaedic research on the screens [27]. Similarly, when projected light marks every single person and shows them where to go, it will not only be intuitively understandable but also open up a more collaborative environment where people can be more social, meeting new people on the way to their intended location, as seen in Figure 8.

Even though the idea in Fig. 8 is only in the concept phase, it is still possible to predict some challenges that should be addressed throughout the process. A similar concept already exists in commercial aeroplanes as emergency exit guide lights. Each seat is assigned to a certain door, and the lights on the floor show which direction people are supposed to go [28]. In the case of a conference, the room layout will likely be more complex than one single corridor. Additionally, the paths of different groups of people will probably intersect on the way. Even though these challenges are complex, they are still part of the design process and do not decrease the existing potential that this concept offers.

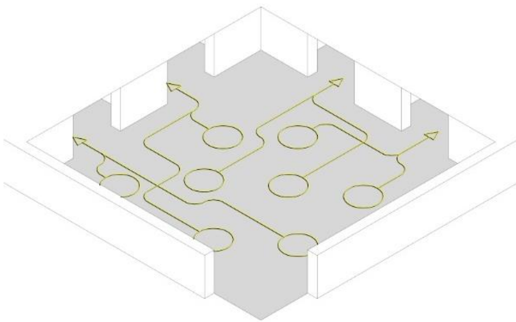

Fig. 8. Wayfinding with light projection.

The second option is to use kinetic installations to communicate with people. Similarly, even though they are not exactly used in the active guide context, there are many examples that prove to be inspirational. Most of them function by reacting to people's movements and proximity to the installation itself. Open Columns, by Omar Khan, is an interactive architecture installation that responds to increasing carbon dioxide levels by slowly descending from the ceiling, guiding people to move to another place [29]. It is a rare example in terms of combining environmental elements with human interactions. Additionally, since it is a column that moves slowly, it is very intuitive for people to understand that they have to move away. Autopoiesis, by Ken Rinaldo, has a network of robotic arms that not only respond to visitors but also to each other. This response is visualised by the end of the arm reaching toward the person close to it [30]. Since it already looks like an arm, a similar structure can be used within an atrium to point in the direction they have to go.

For *physical quality*, interactive guide systems should be embedded and distributed in the architectural space to differentiate from the current navigation systems, such as digital maps on big screens, and become a navigating landmark [31]. Additionally, these interfaces should be interactive to adjust to changing circumstances. The *experiential quality* of these systems should be intuitive since they use our embodied perception, and the experience should be shared since it targets shared spaces. The affordances of interface design should be considered carefully by showing people what they can do with it early on "in order for them to become motivated to cross the participation threshold" [23]. Otherwise, most people stay as distant observers. At the same time, since this concept is designed for crowded spaces, it is important to point out that social embarrassment and interaction time are important aspects that should be taken into consideration [23]. And for *communicative quality*, the interface should provide answers and guidance to the specific question.

5 Conclusion

Making people an active part of intelligent environments is crucial for the further development and acceptance of these systems. The first step, the addition of interfaces, changes the flow of information in the system. The second step, designing these interfaces to cater to multiple people, has a limited number of real-life examples, but at the same time, it is very open to inspirations from other fields that focus on different aspects of these problems. Three criteria, "physical, experiential, and communicative" qualities [13], were used to analyse and discuss the relationship between the interface and the architectural space, and their impact on social relationships. These ideas were supported by multiple theories, including Human-Building Interaction, Adaptive Architecture, and Tangible Interfaces.

The suggested new systems were demonstrated through different use cases and explained through various conceptual projects. Each use case was then analysed according to our criteria. Even though the overarching theme is the same, each use case suggests a different potential and a challenge that should be tackled when these projects are realised. In the case of Distributed Control systems, the new idea offers comfort for many people with different preferences in shared spaces. And the biggest issue is designing an interface in a way that would mediate preference negotiations. Informative Guidance systems included two use cases that were distinguished according to the users' level of attention. Ambient Guide offers a lot of potential for improving existing buildings by collaborating with humans. However, the negotiation part is less mediated by the technological system. Active Guide has much potential for creating a more collaborative environment. The challenge is to design it intuitive enough, so that people can pass the social embarrassment threshold and interact with the system. While the examples illustrating use cases remain conceptual, they offer valuable insights into potential benefits and challenges, laying the groundwork for future research to build upon through empirical validation and user testing.

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