Seminar for Computer Science
Literature Review — Interactive Architecture

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Introduction

> **Interactive architecture** refers to the branch of architecture which deals with buildings featuring the trio of sensors, processors and effectors, embedded as a core part of its nature and functioning. Interactive architecture encompasses building automation but goes beyond it by including forms of interaction engagements and responses that may lay in pure communication purposes as well as in the emotive and artistic realm, thus entering the field of Interactive art.[3]

This includes human-building interaction (HBI), ambient displays, media façades and many types of technology that is designed to interact with and adapt to its inhabitants[6]. The field of interactive architecture encompasses the integration of digital technologies into built environments to allow easy reconfiguration, so as to serve many different purposes[7].

Intersection of architecture and interaction design

These two major fields seem to be separate on the surface, but have been intertwined for a long time and are getting closer to each other with new technology. Interaction design is being influenced by architecture, as interfaces use architectural metaphors, use space more as something to interact with and not just stuff. [8] There are several encounters between HCI, architecture and urban design such as [1]:

- Ubiquitous computing, where interactive digital artifacts are situated in the environment
- Media spaces, where, through video and other forms of media, distance is made less prevalent
- Notions of space for example in virtual reality
- Design and development of virtual worlds
- In learning from architecture to combine form and function as well as the symbiotic relationship between people and artifacts

Architecture is also being increasingly affected by interaction design as technology allows for more interactive systems in buildings. [7] Alavi et al. [1]

also mention that there are overlaps between architecture and interaction design. Dalton et al. [5] discuss the emergence of technology that allows for interfaces, that are not bound to a specific device and/or display. As devices become progressively more diverse in their type of interaction, space becomes a topic of importance that has to be dealt with. *Virtual reality* and many other new types of interfaces like *ambient displays* [8], call for types of interactions that allow usage of these technologies.

Architecture on the other hand rather is focused on space but not as much with individual interaction design. Wiberg [7] writes extensively about these two being intertwined. The first overlaps between architecture and interaction design can probably be found in the mid 1980s with early attempts in *computer-aided design* tools (CAD). These allowed for greater detail to draw, edit, scale, zoom and have many different layers of the same blueprint. With advancements in 3D-print technologies this includes “printing” models and even buildings themselves with help of drones and robots.

Another facet of architecture and interaction design interconnecting are *embedded systems*. These systems are designed to be embedded into our built environment. Recent technologies such as *ubiquitous computing* and *the Internet of Things* (IoT) have fueled this topic to be more present, even though embedded systems existed for much longer than that. The focus is here to enhance rooms or even buildings through implementation of these digital technologies. Many implementations center around mechanics that would lead to more energy-efficient buildings such as smart thermostats. There are also bigger ideas that go beyond temperature regulation, such as flexible walls or *smart cities*.

There is also the architectural influence on the structuring of digital technologies, also mentioned by Dalton et al. [5] A direct representation of that is the game *Minecraft*, which allows the design of architecture in a virtual world. Another portrayal is the use of metaphors in interfaces, such as the *home screen* and the *back* button on smartphones and web browsers, as well as being *away* on messaging platforms.

There is an even more direct connection between the two, which is **architectonic technology**. This takes the idea of technology in buildings of embedded systems even further, and suggests technology that is not just added into buildings but function as a part of the building. These include *media façades* which work as technology that is seen as being part of the architecture of a building itself and not just as an added feature. This enhances the appearance of certain aspects of a building, the whole building or even delivers interactive possibilities, as seen in the ARS Electronica building in

Linz.

Most interaction design projects remain restricted to a mostly fixed size, like web design to laptop screens and smartphones. If we consider technologies that are an inseparable part of the building itself, we have to change our scale, from small objects to buildings. This in turn changes our perception in how to design these things, not only from the point of interaction design, but also from that of architecture. Further, interaction design usually deals with a specific user interacting with an object, while buildings rather deal with many different users interacting with a building, that is fixed in space for a long time. Moreover, architecture is seldom strictly used, but rather inhabited or visited. These concepts are crucial for the design of *architecture elements with interactive capabilities*.

Surprisingly little collaborative work between people from the two disciplines has been done. In recent years this starts to change, as advancements in sensors and actuation systems, IoT, robotic architectural elements and the new user expectations and environmental concerns that call for new life, work, and mobility styles. [1] The notion of *human-building interaction* (HBI) seeks to bridge this gap between architects and interaction designers, in hopes to initiate collaborative projects. In these projects, HBI seeks to address physical, spatial and social opportunities and challenges that emerge from these new environments. As built environments become more interactive there are many facets that have to be discussed.

One section is concerned with *interfaces*. Other than those between the building and the occupants, where change is enacted, there are also interfaces between buildings and their services. As some smart devices do things on their own, the *agency* of those become important. How much control does the user have to change certain behavior? Human decisions and automation efficiency have to be carefully balanced. These devices being implemented directly into key elements of a buildings infrastructure also raises concerns of *security and safety* in case of failure or exploitation.

Architecture and products of interaction design have a very different lifespan, so questions about *compatibility of design processes* come up. Buildings have to be maintained, as well as these new technologies that are now part of that. As buildings change their purpose, how are these elements being used in this new environment? Adding interactive technologies also includes the risk of *adoption*, as there are barriers to the introduction of those. One barrier might be construction norms and standards. These must be observed in the process or must change to allow them.

In the discussion between architectures and interaction designers (and also drawing from philosophy, art, geography, dance, mathematics, computing, and still other domains) emerges the field of human-building interaction that tries to find collaborative solutions with these emerging technologies.

Adaptive architecture and feedback loops

A subset of interactive architecture concerns itself with *adaptive architecture*. Adaptive architecture in this context is defined as *buildings specifically designed to be adaptive to their environments and to their inhabitants.* [6] This definition is broad on purpose and therefore includes even buildings that are not augmented with computing technology.

As Richard Coyne [4] points out, buildings are already quite interactive and adaptive. Activities such as parkour and skateboarding take architecture and use it for how they see fit. Traceurs (practitioners of parkour) and skateboarders observe the structures that have been built for functional or aesthetic purposes and make them *adapt* to their ideas. Richard Coyne mentions these activities and proposes that architecture needs to focus more on the interaction between humans and buildings that are beyond touch, gestures, commands, etc.

Keeping those interactive capabilities in mind, we can chart the field of adaptive architecture. Coyne not only describes the adaptive and interactive abilities that buildings already have, but also examines the underlying ideas that they share. He describes ideas about contest, specifically the type of interaction in game design that is *agon*, which defines battles or fights between people and the environment. These ideas are examined and he pictures the implementation of games into architecture. In implementing those games, designers should think about the interaction between humans and cities, as well as humans and systems.

Schnädelbach [6] also mentions this interaction but goes a step further. In his paper he not only describes how technology can make buildings more adaptable, he focuses on the feedback loop between humans and systems. Oftentimes systems — not limited to ones implemented in architecture — are being deployed without regards to how they are being used in practice. Through recognizing the feedback loop in practice of interaction between people and the system we can greatly improve those systems.

Movement being a particular example, he shows that systems should be flexible to allow for corrections in how buildings are being used. Through sensors in a building, we would be able to find patterns in the movement of people, and make the building itself change itself to adapt. Many occupants may be forced to walk along an unnecessary long path to get to their different destinations. An adaptable building would be able to change walls in such a way to improve routes to make them shorter, or could dissolve bottlenecks.

Schnädelbach points out that all expressions of our behavior are motor acts, while not all behaviors are expressions (e.g. thinking). These motor acts results in movement somewhere in our body and every time we interact with others or the environment movement is involved. In order to better make use of these expressions we need to classify these movements. These movements vary in on many different measurements and scale.

The blinking of eyes or rather the movement of the eyelids themselves are very different from walking where the whole body is involved. Classifying these movements also has to take into account how expressive and detectable those are. As an example he mentions the movement in the gut as being least expressive, while smiling, grimacing and other faces are most expressive. There is also the question about the level of control we even have on some of these expressions. Compare the autonomic nature of our heart to speaking, which is a rather intentional activity.

Another reason in the interest of movement is the fact that elements in architecture are increasingly designed to move. Examples of manually adaptive homes are Rietveld's Schröder house, Holl's Fukuoka housing, and Ban's Naked House, where movement of architectural elements are mapped one-to-one to human movement. Schnädelbach notes, that architectural movements need physical effort and force to trigger.

In prototypes such as TU Delft's Muscle Tower, Ruariri Glynn's Reciprocal Space, and the ExoBuilding, several human movements are technologically coupled with architectural movements. These movements range from respiration to whole-body movements and which those systems pick up through sensor infrastructure. This will be processed through software middle ware to a system for actuation. With those systems, movement in people is coupled to movement in architecture through which an action-reaction feedback loop emerges.

Apart from this coupling, movement behavior can also give us interesting information about their location, spatial relationship to other people, objects and places. Using digitally driven adaptive architecture, such information is being sensed, recorded and stored to enable actuation in architecture. Combined with other personal data, such as physiological, identity, activity, and social networking data it is possible to allow for even better usage of adaptive architecture. It would enable a much better and immediate feedback loop between people's behavior and the behavior of the built environment.

However with so much data from sensors being stored and used, as well as personal data from occupants, data privacy concerns become a factor. A building acquiring these kinds of data makes it even more problematic, because it is less visibly recording, storing and linking data about its occupants. This data could make its invisibly journey to thirds parties without much control or knowledge for those who are being recorded.

Improving communication between humans and buildings

Usually when we talk about interaction design, we are talking about a screen with an interface that we control. Through implementing interactive technology into buildings, this is most often the default solution to how to control things. This may work but in architecture we have much more possibilities that we can take advantage of. In their paper Wisenski et. al [8] introduce *ambient displays* as an usage example.

Ambient displays take advantage of other types of interfaces that don't rely on displays. They use the entire physical environment as an interface to interact with all kinds of senses. In Wissenski's prototype called *ambientROOM* they introduce a room that relies on *ambient media*. This media includes ambient light, sound, airflow and physical motion that should be working as peripheral displays. As those ambient media channels are emitting information, they should work at the background of user attention.

Through this technology of ambient displays, there is a push to separate background and foreground information. Using displays for information that is background and foreground makes it harder to separate those two things as they both have to share the same device or display. Ambient displays allow for background information to really be in the background and opens up possibilites for a better fine-grained separation. Examples of such an implementation could be air-conditioning, introducing the functionality to convey information through the changes in airflow. One usage would be to improve human interaction as ambient media could show human activity. Subtle changes in the room could convey such information without it diverting as much attention if not necessary.

With such a way of implementing information into rooms and buildings, we have much more alternatives when it comes to conveying information from a building or room to its occupants. Through tracking of inhabitants activities, the interaction experience of those could be greatly enhanced. [1] In combination with adaptive architecture this could lead to a great improvement in how humans communicate commands to buildings and how buildings communicate information back and execute those commands. Automatic sliding doors for example don't need direct manipulation by humans and only rely and sensors to detect presence.

Conclusion

Interaction design and architecture have more and more topics that need both their expertise. Fields such as interactive architecture and human-building interaction emerge, that require architects and interaction designers to meet and share ideas. These groups already got ideas inspired by the other but rarely work together on projects. Many projects could profit from a deeper collaboration and enhance each others perspective on their respective field.

Finding the overlapping themes in interaction design and architecture will help in constructing better designed future interfaces and buildings [5, 7]. Building should have more interactive capabilities, which would result from this collaboration, such as spatial, social and physical impacts. [2] Enhancing architecture is not only a concern while planning its construction, but also long after its in use. Allowing buildings to be adaptive, to be malleable after finishing construction allows for better insights and enhancement of buildings. [6] In enhancing our understanding of human-building interaction and their built manifestations, such as ambient displays, this would have positive results.[1, 8]

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Interactive Architecture

State of the Art

Seminar Computer Science

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The RAM House

Figure 1: Ram House Prototype

The future of homes is most often described as being connected to an increasing number of digital devices, rising connectivity and the infamous term of permanent connectedness. Many projects developing the assumed future of the home do not take a basic human requirement into account: privacy. Homes have always been a place of non-digital privacy. You can lock doors, close curtains and become virtually invisible to an outside gaze. The digital age changes these circumstances. Today connected devices "follow" you into your home and keep a connection to the outside.
Most designs for future homes strife to increase the amount of connectedness, using smart devices that also communicate with the outside world permanently.

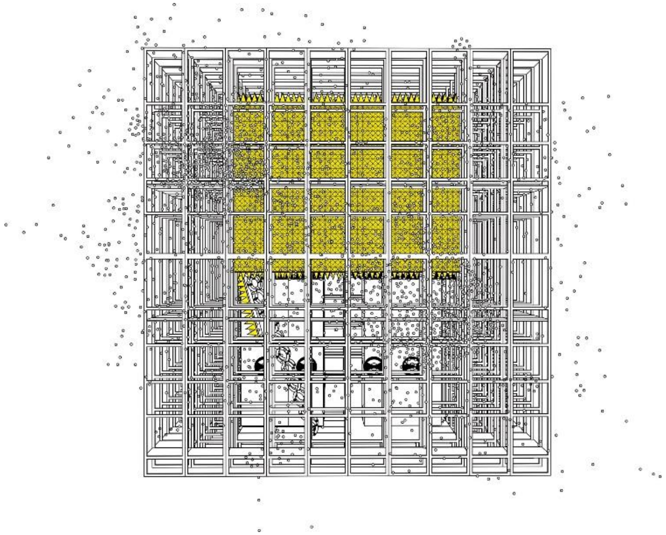

Figure 2: Ram House Schematic showing Faraday Cage

The ram house takes our current societal as well as digital development into account and tries to extend the human need for privacy to a digital level. Parts of the house (a prototype) is built using materials capable of absorbing electro- magnetic waves as well as a faraday cage. The absorbing parts can be shifted according to the inhabitant's requirements making it possible to shift between becoming invisible to the outside digital world and having normal connectivity as in any standard house. The target is described as giving people back their digital autonomy in a future in which the digital gaze into the living place will be much more present and potentially revealing than the conventional one.

The Numi Toilet

Figure 3: Numi Toilet in real Setting

Toilets are often thought of being something simple which do one not too glamorous task: taking away our bodily waste. The future home should improve every aspect of everyday life to benefit the inhabitants. As the main theme of the subnetTalk describes, it is important to go beyond what we currently envision when talking about the home of tomorrow. And when doing so we realise that there is capacity for innovation in areas that do not immediately come to mind. One of these areas are toilets. While smart toilets have already been a huge thing in Japan for quite a long time, the western world has not quite realised their potential. Now as home improvement and optimisation are becoming ubiquitous, many areas are discovered as being worth improving. One of these areas are toilets. One example is the "numi” toilet by Kohler. First of all, this is not the only bathroom component by Kohler. They target a room long neglected by the smart home community. With their "numi" toilet they create a striking example of incorporating functionality that is not apparent in the respective product type. This particular toilet achieves two main objectives. Not only does it improve the product with respect to its original purpose, but also adds functionality not related to this very purpose which improves the experience. First, the toilet integrates components that have been around in Japan for a long time. These include bidet functionality, dryer, a motion-activated-cover as well as a heated seat. Additionally, it includes features for more comfort including a foot warmer and illuminated panels. These panels change colour based on the time of day and personally set options targeting a more relaxed experience. All this functionality is controllable through a touch-remote which also stores presets for several users. Further, more unseen features include speakers to play music and the possibility to connect to Amazon's Alexa, giving the ability to control functionality with

Figure 4: Numi Toilet LED Lighting

one's voice making the whole experience hands-free. Of course, one could ask if all this is necessary if it even serves any purpose. According to Kohler their philosophy includes making everyday activities more enjoyable and thus improving the quality of life. A major point in designing and developing smart home appliances and technologies is the focus on energy and resource efficiency. Many smart home solutions try to increase efficiency and optimise power consumption e.g. smart heating controllers. The “numi” toilet includes two flushing modes and uses the reduced mode if not instructed otherwise. This helps cut fresh water consumption. On a global scale reducing the amount of water used by toilets could potentially have a huge impact. At this point the “numi” toilet has to be seen from a different perspective. It is a ridiculously expensive product, which will without any doubt not reach a high enough number of sales, to have a big impact on our lives. This is also not the point. The reason it is included here is to show an approach to the future home, which introduces change and innovation in an area not thought about very often. It demonstrates that improving interactions is not limited to what is apparent, since it introduces features not related in any way to the standard model of toilets.

Figure 3: Numi Toilet in Compact Form

Infrascan Smart Toilet

We now see a different approach to a vital component of our homes or buildings in general. while the “numi” toilet by kohler is an example of how comfort can be improved and optimized in future homes, the infrascan smart toilet shows what future home inventory can do for our health and the planet as a whole. Both are areas in which future "smart" homes and buildings should have an impact. They are not only supposed to increase comfort and connectivity, but also to completely change the way we interact with our home inventory.

Figure 4: Infrascan Smart Toilet

The infrascan smart toilet creates a new means of interaction which is implicit in something we do and actually have to do every day without us having to change anything in our way of life. It just introduces a new method of interaction without humans having to adapt. Now, what does it do? This toilet does two things besides the usual. On one hand it analyses bodily wastes to determine the user's health and on the other it introduces a novel flushing mechanism designed to make the use of water obsolete.

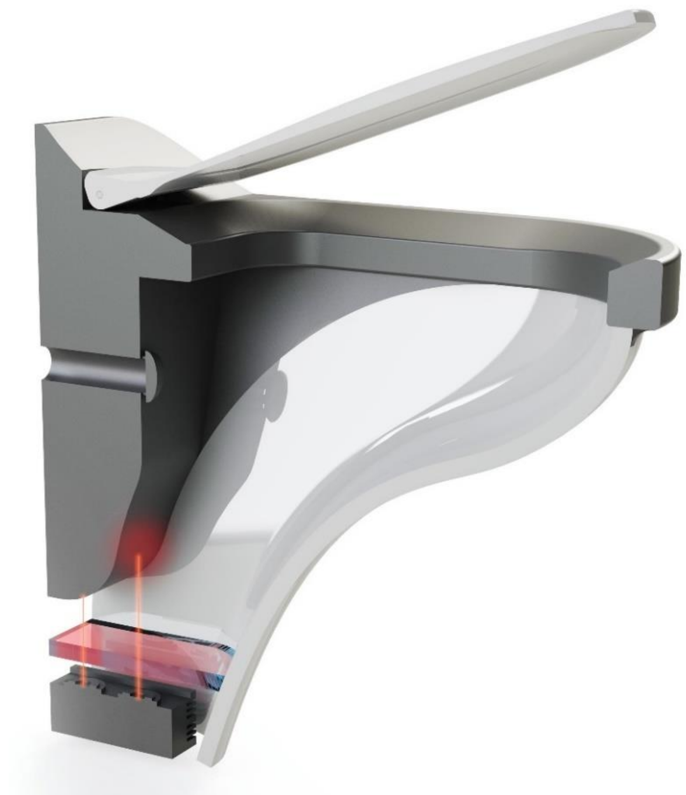

Figure 5: Infrascan Analysis

First of all, flushing is done using supercritical CO_2 which is in between liquid and gas state. The toilet can be sealed by the lid and pressurised to make supercritical CO_2 possible. The benefit being that obviously no water is used. CO_2 has a very low surface tension making it spread out across the toilet surface to clean it. It is then sucked into a chamber, filtered and put back into a gas state for storage. Unfortunately, the designer does not specify how waste is transported from there, but since this is only a concept, we will ignore this lack of explanation for the time being. The other function is analysis of bodily wastes. This follows the trend of analysing human body functions, as already done by "smart wearables", but much more implicit and frequent. Analysis is based on infrared scans and Fourier Transform (FTIR) to get the wavelength spectrum of the waste. This spectrum can then be analysed to find anomalies. What makes this approach special and stand out is the frequency in which samples are taken and analysed, which is basically every time the user goes to the toilet. This approach follows the general approach of collecting large amounts of data. The infrascan smart toilet can also be linked with one's phone to sync and visualise data which can then be accumulated over a long timespan to help show and interpret changes potentially indicating health problems. This toilet shows that the future home can do much more for us than just improving comfort and reducing workload. By introducing a novel, implicit form of interaction it can help us live healthier lives as well as potentially reduce our impact on the environment.

MIT CityHome Project

Figure 6: CitiHome Gesture Control

The following project is no longer active but contains many concepts potentially important for future homes. The CityHome project introduces an approach to the future of small homes. This concept contains several modes of interaction as well as the ability to maximise available living space. In a world in which city populations rise, available living space becomes scarce and prices skyrocket (e.g. New York, London or Vienna), maximising available and affordable living space is definitely an important step towards the future home. The city home project offers a solution to this space-funds-problem. Their design promises to potentially triple living space in small (even one room) apartments by eliminating the premise of having different rooms for different activities. The CityHome project turns a single room into multi-purpose living space. This is achieved by a specially designed "wall". This wall contains different components required in a home e.g. bed, table, seating etc. which can be stored and extended depending on the current requirements. In addition, the wall itself is movable making it possible to change the size of parts of the room (e.g. enlarging seating area and reducing the size of the bathroom). Changing the room's layout also enables the occupant to change if the kitchen is embedded in the room or separated again based on the current requirements. The wall features many more options for customisation. It can for example retract all deployed accessories and move itself into a corner maximising the space available. This space can then be used as personal workspace, for working out or even throwing a party. Besides managing available space CityHome does even more: it also sports lighting which can be adapted to the current situation (party vs. work). All the aforementioned features including transformations, retractions, changes of lighting can be accomplished using hand gestures.

Figure 7: CityHome Example Configuration

Intellithings Roomme

Now we discover a project which completely changes the way we interact with our homes. Smart appliances can do many things for us, including playing music, adjusting temperature, or lighting mood. Originally all these

Figure 10: One Sensor per Room

components had to be addressed separately via some interface. In recent years we saw the rise of assistant devices like Amazon's Alexa or Google Home which are able to interact with all these different smart home appliances consolidating control into a central device the user can interact with. In addition since the main benefits of these smart home assistants are their voice recognition capabilities users can use them to control their home environment. This is of course fine, but still not seamless; the user still needs to interact with the controller. Intellithings' roomme follows a different approach in which interactions become implicit. Abstractly talking a room becomes aware of the person inside and automatically sets the environment to the specific person's preset. This seems to be the logical next step to smart homes. Explicit interactions with homes or rooms become obsolete.

Figure 11: RoomMe Sensor

Rooms automatically adjust to occupants. The question remains: How does this work? According to Intellithings a single sensor is placed in any room to be controlled. There is no face recognition involved. Actually, the sensors do not identify people at all but rather their phones' Bluetooth signature. Every sensor builds a Bluetooth fence at the room entrance and monitors incoming and outgoing Bluetooth enabled devices. Should an incoming device match a stored signature, the corresponding person's settings are applied. The sensors come with a smartphone app in which behaviour can be configured. These settings can be quite specific e.g. "When I enter between 5pm and 9pm, set temperature to a certain value".
Any supporting device could then be set to a certain state when the user enters. This cold also include a coffee machine e.g. some people like black coffee, some prefer cappuccino. Roomme could potentially turn on the coffee-machine when the user enters the room at breakfast time and apply the stored settings. Roomme also includes some artificial intelligence. According to Intellithings settings can not only be set by users, but also

learned over time. There is no explanation to be found on how this actually works, but an intuitive solution would be sensors monitoring their connected devices and learning settings from patterns in which users adjust them. These settings can then be set automatically for the user. So potentially roomme could completely automate home automation requiring only installation of sensors and one-time pairing of phones and devices to control. The sensors would then learn and at some point, no further user interaction with any controlled appliance would be necessary.

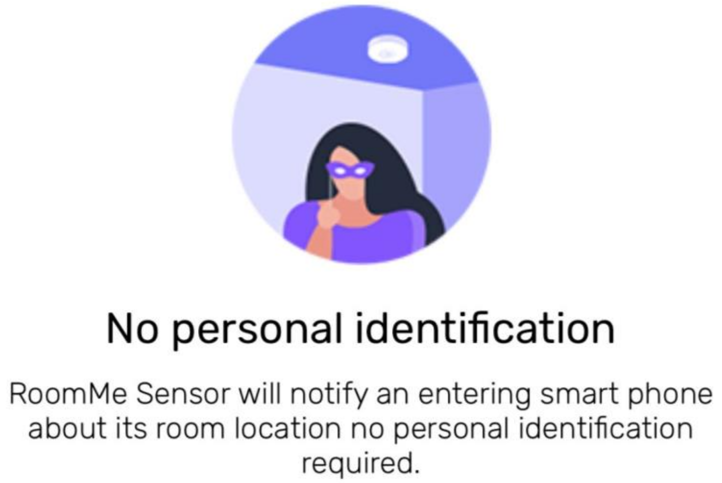

Figure 12: Commitment to Privacy

Roomme also fulfils a different requirement. As awareness of the importance of protecting personal data increases, we do not want to share our room-preferences with others. Roomme stores everything locally. There is no communication with the outside world at all, except for updates of course.

There is one negative aspect which cannot be ignored: Roomme does not identify people which is good concerning privacy, but it also requires everyone to carry their phone around permanently in order to be recognised. Summarising, roomme incorporates many innovations in home automation into one product introducing implicit interaction without human actions, utilising artificial intelligence and respecting the user's privacy by keeping data local.

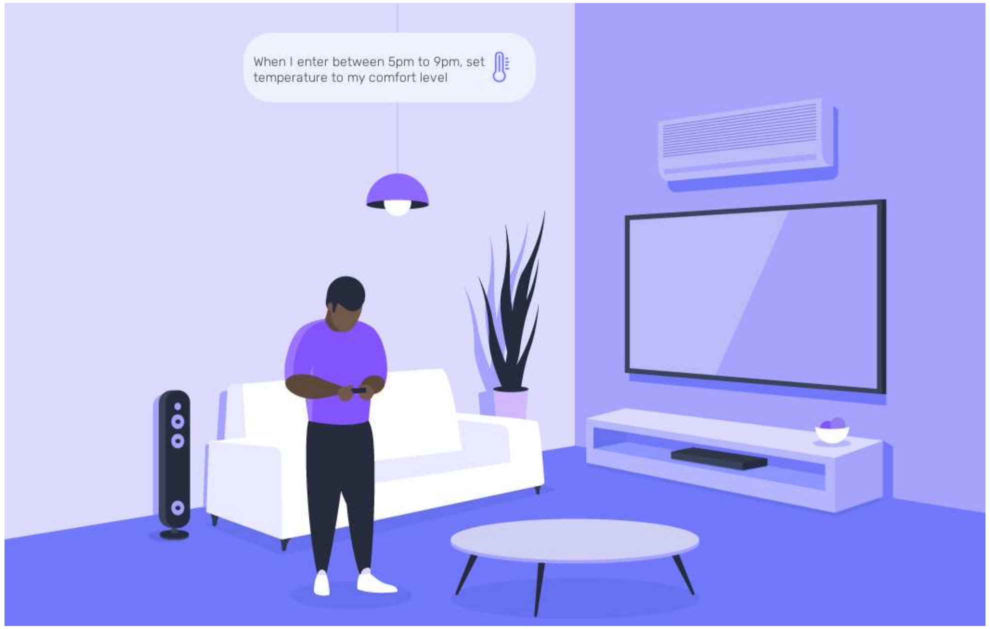

Figure 13: Example Scenario

Interactive Floors

Figure 14: A Game Application

The idea behind this is to project texture on a floor indoors, capture people's actions and react to them. This section is not about a specific project, but rather the whole array of available products in this area. This approach covers something we use all the time: floors in our homes or offices. Now why should these surfaces not be used in a smart way. This is probably also what creators of many of these projects thought. So how can projections on floors be useful? Of course, projections can be used to create all kinds of games or fun interactions with natural materials like water or grass. But apart from applications used in leisure activities there are also many professional uses for this technology. An example would be physiotherapy. Patients are often reluctant to engage in physio due to it on the one hand being a slow process and on the other hand because of the

Figure 15: Application with Interactive Water

pain sometimes related to it. Floor projections could be used to simulate water or some other material which reacts to their movements for example immediately giving feedback and motivating patients to strengthen their efforts thus increasing the rate of recovery. One different application we do not want to get into extensively are advertisements. Interactive advertising could be unbelievably effective since (we are no psychologists, but) consciously interacting with something for example by walking over it makes it a lot more rememberable than just viewing it.

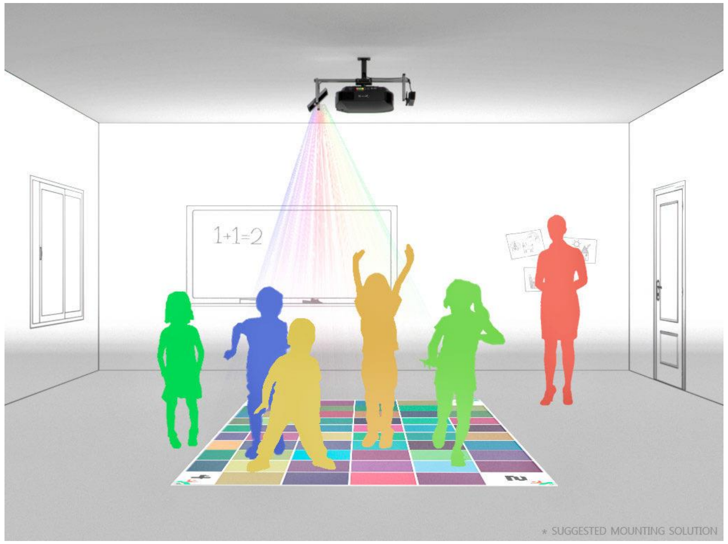

Figure 16: Schematic Description

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Seminar for Computer Science
Logbook

András Czuczi, Samy Dafir, Andreas Lindlbauer

January 26, 2019

András Czuczi: Interview + Summary SubnetTalk

Samy Dafir: State of the Art Review

Andreas Lindlbauer: Literature Review