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Interactive Play Environments: Digitally Augmenting the Built Environment to Mediate Play

Master's Thesis

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Abstract: This master's thesis expands the field of research in *interactive playgrounds* by examining the role of the *built environment* that is augmented with *digital technology* for richer interaction possibilities in such playgrounds. Based on a literature study, this thesis distinguishes *interactive play environments* from interactive playgrounds, since these often do not reflect the impact of the environment on play very well. The research question being raised is then as follows: "How do children use the digitally augmented built environment in their play?"

The thesis describes the process of designing and prototyping an interactive play environment that features *communication* and a *tube* to throw objects through as play concepts. Six different prototypes shape the interactive environment in close interplay with landscape and existing built environment. The prototyped environment is then evaluated in a 4-day study at a Swedish school with approximately 240 children during their recess times. This study uses *observation* as the predominant data gathering method. The gathered data are analyzed based on *content analysis*. As an answer to the research question, this thesis describes the play that happens in an interactive play environment and draws conclusions on the influence of such an environment on play.

The results of the study indicate, that the digitally augmented built environment has an impact on play in stimulating certain new play patterns. It shows its potential mainly as a mediator between the children and the environment, thus stimulating children to explore their environment through play and discover dormant values of the environment. Although we found that the digitally augmented built environment *influences* play, this study can not confirm that the digital components embedded in the built environment actually *improve* the play. However, the increasing presence of digital technology in society in general makes it inevitable to think about how this presence should be reflected in children's playgrounds in the future and this work can give some directions for that.

Keywords: Interactive Playgrounds, Play, Built Environment

CONTENTS

PREFACE

This thesis is embedded in the project *"Digitala och fysiska lekmiljöer"* (Digital and Physical Play Environments, *DigiFys*), an interdisciplinary research project examining the opportunities of playgrounds that are combining physical and digital play. The project, funded by Vinnova[1], is a collaboration between the Royal Institute of Technology (KTH), the Swedish University of Agricultural Sciences (SLU), Uppsala University (UU), the real estate company NCC Construction Sverige AB, the playground manufacturer HAGS Aneby AB, the landscape architecture bureau URBIO AB, the IT consultancy company HiQ Stockholm AB and the municipality of Huddinge.

The DigiFys project influenced this thesis work and vice versa in many ways. The play concepts that served as a base for the prototype design are part of the larger project context. *Communication* and the *tube* have been selected based on background research, ideation in a number of courses at KTH and participatory design with children from the target group (6–11 years). Also, the close collaboration with industry—mainly HiQ, HAGS and URBIO—arose directly from the project context. The evaluation results will now feed future work in the DigiFys project. Additionally, the prototype design itself will be used as a base for further developing and evaluating the concepts.

The close interrelations with the DigiFys project led to some design decisions that have not been entirely focused on the research question of this thesis. Additionally, the prototype design also had to meet the criteria of another master's thesis in the same project context that focuses on the effects of interactive playgrounds on long-term engagement of children [1]. Therefore, not all design decisions and goals stood in direct relation with this thesis. These mentioned trade-offs will not be further discussed in this report but the reader should still take note of them. A description of the contribution of the different project partners will be given in chapter 4.

1 `http://www.vinnova.se/sv/Resultat/Projekt/Effekta/2011-01544/Digitala-och-fysiska-lekmiljoer1/`

1 INTRODUCTION

Play is an important part of childhood and has great influence on the physical, mental and social development of children [2, 3, 4, 5, 6]. The increasing presence of digital technology has caused significant changes in children's play in the last decades—from explorative outdoor play towards a more sedentary play indoors, often relying on computers or game consoles [2, 7]. Although computer games can facilitate equally valuable ways of playing, it is proven that completely excluding outdoor play has negative impact on the well-being of children, both physically and mentally [7]. Incorporating technology in the outdoor environment is a potential way to combine the social and physical advantages of classical outdoor play with the appeal of computer games [2, 7, 8], thus making outdoor play with peers more attractive to children again [7]. This approach, being used in *interactive playgrounds*, has recently gained much interest among researchers.

An interactive playground is commonly defined as a space in which physical play objects that are augmented with digital technology stimulate play [7]. Often, these playgrounds focus on *open-ended play*—a form of play without predefined goals or rules, thus leaving room for creativity and encouraging children to invent their own games [2]. Open-ended play is a key ingredient to successful playground design in general [9, 10] as well as interactive playgrounds in particular [8]. This thesis expands the view on interactive playgrounds by examining the role of the *built environment* in these playgrounds.

The built environment, broadly defined as "the human-made space in which people live, work, and recreate on a day-to-day basis" [11], includes in the setting of an interactive playground all human-shaped landscape as well as all architectural structures in the playground, such as play houses, swings or slides. Augmenting the built environment with digital technology opens up new possibilities to interact with it. These interactive environments become "spaces in which computation is seamlessly used to enhance ordinary activity" [12]. Architectural research argues further, that "the built environment can be seen as a behavior setting—a setting for human activities" [13]. Since the setting in which the play happens is proven to have significant influence on the play that happens [14, 15], it is interesting to see what exactly this influence is.

The contribution of this thesis lies in exploring *interactive play environments* that go beyond interactive playgrounds by explicitly addressing the digitally augmented built environment and its role for play. It aims to examine and describe how the digitally augmented built environment with its novel interactive capabilities influences play. Altogether, this shapes the research question of this work:

"How do children use
the digitally augmented built environment
in their play?"

2

RELATED WORK

The three main ingredients of an interactive play environment are the built environment, i.e. the space consisting of the man-made natural and artificial elements (landscape and play structures), the technology used to create interactivity, consisting of sensors and actuators, and the play itself, which should, based on research in the field, focus on open-ended play. This relation is shown in figure 1.

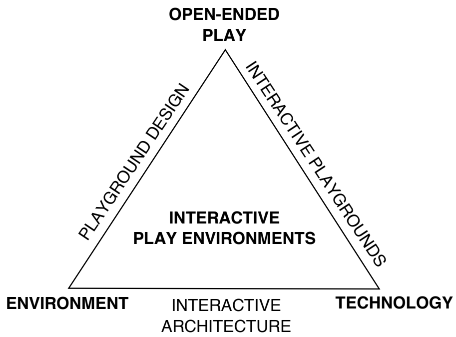

Figure 1.: The triangle of interactive play environments

Currently, each of the three fields at the corners of the triangle is very well researched on its own but research in the combination of all three is still in its infancy, especially since related work on interactive playgrounds often focuses on the influence of interactive play objects on open-ended play, thus overlooking (or at least not explicitly addressing) the role of the environment. To cross the boundaries between technology, play and the environment, this section will introduce related work from the three different overlapping fields on the edges of the triangle. First, it discusses interactive playgrounds, combining technology with open-ended play. Second, it considers conventional playground design, taking into account the relation of the built environment and open-ended play. And third, it introduces work on interactive architecture that covers the combination of the built environment and interactive technology.

2.1 INTERACTIVE PLAYGROUNDS

Related work in the field of interactive playgrounds is often based on user studies with certain interactive play objects. The influence of the environment plays a subordinate role in most related work. Especially, the user studies on interactive playgrounds rarely take place in an actual outdoors playground setting but rather in gyms [4, 16, 17] or even lab settings [18], thus neglecting the influence of the environment on play. Even the few studies on interactive playgrounds in outdoor settings often focus only on the digital props and the play with them [19, 20, 21]. However, the space itself

plays an important role for the play [8] and should thus be part of an evaluation. The focus of this literature review lies therefore on projects where the role of the environment is not entirely ignored to get as close as possible to the focus area of this thesis.

Significant work on interactive playgrounds involving the environment has been done by Seitinger et al. in the *Reactive Playground Project* at MIT. Their work focuses on the relationship between children and the play environment mediated by animated playground props. They examine the ability of such interactive objects to "enhance open-ended and physically active play in playgrounds" [8] and introduce *Space Explorers*, a class of interactive play objects that stimulates children to explore the environment [8]. Furthermore, with the *Interactive Pathway*, an interactive play installation that visualizes movements, they incorporate a participatory approach into the design of interactive playgrounds and also recommend that for future work [20]. As consequences of using interactive elements in playgrounds, the authors mention increased physical activity, high engagement level of the children as well as the exploratory nature of the activities performed. These consequences conform to the main goals of this work. Also, the abilities of the space explorers are interesting to our research, because they show how digital artifacts as part of the built environment can mediate the relationship between child and landscape.

Another piece of research that explicitly includes the spatial component of play are the *Water Games* presented by Parés et al. [22]. The concept involves the entire environment and features interactive water fountains that can be invoked by groups of users holding hands while moving around the fountains. Here, the interaction itself is seen as a medium: The researchers argue for its ability to communicate meaning by experience [22]. This highlights the importance of good interaction design for interactive play environments.

One recurring concept in interactive playgrounds is interactive tiles that give light feedback using inbuilt LEDs. This approach of using modular building blocks that together form the game [23] is used in many interactive playground designs, including *GlowSteps* [17], *The Body Games* [24], and *Playware* [23]. The important conclusion from these projects is that decentralized play environments—such as the one prototyped in this work—are suitable to support open-ended play [17].

Other projects feature interactive play objects that are either immobile, thus being more connected to the space (e.g. the *SmartGoals* [4], simple poles forming a goal that light up when something is passing between them or *FlashPoles* [7], poles that light up when buttons are pushed or rotated) or mobile (e.g. the *Ledball* [7] or the *Morels* [25]), both having the ability to support open-ended play. The common property of all these objects is the simplicity of the interaction that is seen as a catalyst for open-ended play. Coming from that, our prototypes feature just a very basic set of interactions.

2.2 PLAYGROUND DESIGN

Successfully designing a playground is highly related to organizing the play environment well [8]. Since there is many different kinds of play, the playground has to be diverse in its appearance and usage possibilities and furthermore separated into different zones, for example separating zones for noisy and physical group play from zones for the more silent individual

play [26]. The interactive play environment we built during this thesis work features therefore different zones that accommodate different play activities.

Not only this diversity, but also several other factors determine the playground quality from a landscape architect's point of view: The sheer size of the playground area plays a role as well as vegetation and topography that need to be playable and diverse. Furthermore, it is important that the play structures are well integrated in the landscape and that the playground offers possibilities to get an understanding of the environment [27]. Additionally, research often underlines the need for loose natural material in the playground that can be used by the children to assemble their own play stories and form the environment [14, 28, 29]. One of the concepts being prototyped during this thesis project puts thus special focus on involving loose material in the play.

In their standard work on playground design, Heseltine et al. mention a crucial aspect of playground design: to not over-design them [28]. They point out, that an informal space, such as a natural environment, provides "the opportunity for children to create their own play" [28]. Also, Frost highlights the importance of natural environments for play and defines the term *Playscape* as a landscape that affords play [30]. Fjørtoft et al. even see the natural environment as a play setting that is superior to all man-made structure [31], especially for children's motor development [32]. This all indicates the importance of the interplay between child and landscape. Therefore, this work focuses on the digital augmentation of entire play environments rather than just playgrounds.

2.3 INTERACTIVE ARCHITECTURE

The field of interactive architecture researches all kinds of digitally augmented architectural structures that offer interactive capabilities, thus stimulating the dialog between the environment and its inhabitants. Interactive architecture is situated in the tradition of *Ubiquitous Computing*, first described by Mark Weiser [33]: The computational capabilities of the space vanish to the background, the entire space is getting interactive without being obtrusive.

Regardless of the space being digitally augmented or not, the interaction between person and environment always happens in both directions, thus emphasizing the "symbiotic nature" of the relationship between human and environment [34]. Research sees a strength of interactive elements being able to instigate "new evocative and 'emotive' relations with the built environment" [35]. As for the area of interactive playgrounds, "it should be possible to design ambient entertainment applications in which the player's feeling of presence within her own body and her actual environment is strengthened." [36].

The influence of the environment on its inhabitants goes even further. Interactive spaces have the capabilities to encourage social interactions [36, 37] or, even broader, "an interactive architectural environment can not only facilitate lifestyles and behaviors, but also influence them" [37]. Therefore, an interactive play environment should be able to influence play while encouraging social interactions between playing children.

In order to design the interaction between person and environment, both directions—control and response—have to be considered carefully. The aim of this design should be to make the user forget about the digital nature of the interface, so that "there is no feeling of being the user of a com-

puter application, but manipulating a reality itself" [38]. Natural interaction paradigms, using the affordances of the physical world [39], facilitate this. Although children have a different perception of space [8], this feeling of immersion also applies to them, being able to fully lose themselves in the flow of playing games [40, 16].

Feedback—or response—from the environment is another important design dimension [41]. Multiple different feedback modalities should be applied in interactive spaces in general [38] and interactive playgrounds in particular [42] in order to convey the feedback sufficiently. Currently, light and sound are the two most commonly used modalities for feedback in interactive environments. Both modalities transport meaning of feedback very well but can also directly trigger behavioral change [38].

A significant strength of both sound and light is their ability to influence the ambient mood of an environment [43, 44]. The characteristics of a space are shaped through sound and light that can be either very subtle or very present. Similar to landscape or the previously mentioned playscape, researchers introduced the two terms *soundscape* and—less commonly used—*lightscape* that describe this relationship [43, 45]. A lightscape in particular has the ability to orchestrate movements in a certain environment and can influence social behavior of the inhabitants of that environment [45]. The soundscape, being more immersive by its auditory nature, can similarly influence behavior and also form the understanding that the people have of an environment [46]. An interactive play environment thus benefits from the abilities of soundscape and lightscape.

3

FINAL PROTOTYPE DESIGN

The final design of our interactive play environment was used in the final evaluation that will be described in chapter 6. This chapter discusses the underlying concepts of the prototypes, describes their implementation and their relation to the environment and justifies relevant design decisions.

3.1 CONCEPTS

The two underlying play concepts of our prototypes are *communication* and a *tube* that allows for throwing through all different kinds of objects and materials. Both concepts are aimed to support open-ended play. Figure 2 shows a visionary representation of both concepts being embedded in a natural playscape.

Figure 2.: Vision of a play environment embedded in the landscape by the landscape architecture bureau URBIO

3.1.1 *Communication*

The communication concept exploits the significance of communication for social play and connects different areas of a play environment with audio transmission. Almost all social play situations involve communication of some kind. In playgrounds, communication happens naturally through speech: Talking, shouting or yelling are widely used means of verbal com-

munication during play [14]. The communication concept aims to combine the rich expressiveness of verbal communication with digital technology that allows for data transmission over long distances and offers full control over the communication, its direction and flow.

The protocol of the communication is a hybrid between telephone and walkie-talkie. The interaction copies the push-to-talk principle from walkie-talkies. However, unlike walkie-talkies and similar to telephones, in our communication concept it is possible to direct the communication to a certain partner and not just broadcast to everyone. Additionally, the communication channel can be open in both directions, thus both communication partners can speak at the same time. Therefore, turn-taking is not delegated to an interface level, as for walkie-talkies. Furthermore, our concept allows for multi-directed calls: More than two communication partners can be involved in a call at the same time, allowing for group conversations.

The communication concept uses feedback in two modalities: Sound and light. The aural feedback communicates state changes in the communication. It employs *da-ding* sounds (i.e. sequences of two notes of different pitches) that go up when communication starts and down when it stops. Light feedback indicates the current state of the communication. When there is no active communication, the lights slowly pulsate, resembling the breath of a resting person. This indicates that the system is ready and can be used. Incoming communication from another communication station is represented with quickly pulsating light. Outgoing calls are indicated by the lights being constantly on. If the channel is open in both directions, the light feedback combines incoming and outgoing communication by subtly pulsating on a generally very high level of brightness.

3.1.2 *Tube*

This concept employs a tube that gives light and sound feedback when children put different materials through. The concept is designed to support explorative play and affords involving natural material available in the playground environment (fig. 3). The purpose of the tube is not further defined, however we envisioned it to be a metaphor for all different kinds of processes from the everyday experiences of children in our target group, such as feeding animals, fueling a car or a space ship or charging a battery.

Figure 3.: Children's collection of natural material in a school yard

The feedback of the tube communicates the *action* of throwing an object through as well as the *activity* of the tube, i.e. how frequently it is used. The activity level is reflected with smooth transitions in both lightscape and soundscape. With increasing activity, the soundscape gets more present and active and the animated lightscape pulsates faster and faster. Over time, the activity level gradually decreases again.

3.2 IMPLEMENTATION

The interactive play environment as used in our final evaluation contains six interactive prototypes: Three communication nodes and three tubes. The prototypes feature different form factors and themes that support the *zoning* design principle of playgrounds. The design of the zones is influenced by the natural prerequisites of the evaluation location—a school yard of an elementary school south of Stockholm. The prototypes are placed in three zones, the *mountain zone* on top of a hill, the *water zone* in the vicinity of a small water canal that runs through the school yard and a *portable zone* that is not bound to a specific location (see figure 4).

Figure 4.: The location of our evaluation with the two stationary zones on top of the hill and by the water canal marked in white and blue

Each zone accommodates one communication node and one tube which are specifically designed for this zone. Additionally, the zones have certain characteristics in three different dimensions. First, the placement in and the shape of the landscape influences the appearance and thus also the general impression of the zone. Second, an artificial soundscape matching the landscape supports this impression. Unobtrusive ambient sounds that are being played constantly belong to this soundscape as well as the sounds bound to certain events, such as communication start and end or material falling through the tube. Third, the color of the digital lightscape in the zones matches with the overall characteristics. Light feedback indicates the state of the communication and the activity level of the tube. Altogether, landscape, soundscape and lightscape shape the theme of each zone.

3.2.1 *The Mountain Zone*

This zone is designed for a very visible spot of the playground on top of a hill, next to a forest. The landscape includes a steep slope that accommodates the tube and a flat plateau as a base for the communication station. The raised position and high visibility of the zone give it a stage character that is picked up by the physical appearance of the communication station.

The soundscape in this zone reflects, as in all other zones, the characteristics of the landscape. As one is especially exposed to weather conditions in higher realms, the ambient sound reflecting the activity level of the tube is inspired by different weather and natural conditions. Low activity of the tube is reflected by the sound of singing birds in nice weather. With increasing activity, rain and even thunder are added to the soundscape. Objects falling through the tube trigger sounds of falling gravel or rocks, thus fitting into the mountain theme as well.

The predominant color of the light feedback in this zone is white. This reflects the weather conditions of clouds, wind and snow that often occur up in the mountains.

In order to support the physical visibility and stage characteristics of the area, the communication node features a very obvious type of interaction, using a speaking funnel as known from conventional playgrounds and two hand-sized buttons mounted to a speaker's desk (fig. 5). This rather present interface aims to provide great affordance and invite for play.

Figure 5.: The communication station on the mountain features a speaking funnel and two buttons mounted to a speaker's desk

The speaking funnel is mounted to a wooden pole. It contains a microphone and has white LED strips for light feedback on its front and backside. The speaker's desk is connected to the funnel and additionally rests on two shorter wooden poles. The two buttons that are mounted to the desk are surrounded by five white feedback LEDs each. The buttons consist of three tiny buttons from an Arduino prototyping kit that are wired up in parallel and glued to a laser-cut wooden circle of 10 cm diameter. This larger

button is then covered with waterproof foil and topped by another laser-cut wooden circle of the same size which has a visual representation of the corresponding communication station engraved on its top.

Underneath the desk, there is a compartment that contains the speakers for sound feedback, an *Arduino* board that reacts to button pushes and directly controls the light feedback as well as a *Raspberry Pi* single-board computer that handles audio playback for feedback and communication based on commands it gets from the Arduino over a serial connection via USB.

The tube in the mountain zone makes use of the natural conditions of the zone. It is placed on the steepest part of the mountain and nestles up against the slope (fig. 6).

Figure 6.: The tube on the mountain is very long—about 4.5 m

The tube is about 4.5 m long and emphasizes the terrain with its sheer length. It is made from wooden planks, giving it a square shape and consists of three interconnected modules, thus making it more portable and easy to clean.

One of the modules is interactive with three different sensors sitting in it: A water sensor to sense wet material or liquids in the tube, a piezo disc, functioning as a vibration sensor that detects the vibrations caused by heavy objects falling through and an infrared light barrier that detects virtually all different materials falling through the tube. Each sensor triggers a different sound when being excited.

The interactive module has a wooden compartment wrapped around it close to its top that accommodates a set of speakers, an Arduino and a Raspberry Pi. The Arduino reads out the sensor values and sends a message to a Raspberry Pi when a falling object is detected to trigger sound feedback through the speakers. The Raspberry Pi additionally plays back the ambient sounds according to the activity level of the tube that is again sensed and calculated by the Arduino. The set of speakers dedicated to the ambient sounds is hidden in a tree in the vicinity of the tube, thus making the sounds truly ambient and audible at both the tube and the communication station.

The other two modules of the tube are physically built in the same way but without sensors and only serve as a means of prolonging the tube and nicely fitting it into the environment.

3.2.2 *The Water Zone*

The water zone is designed for a relatively open area with access to water. The focus here is on water as a material for the tube as well as ambient interaction for the communication. The landscape is characterized through a small water canal that leads through the zone and is fed by rain water. Close to the canal, four large trees define a space that accommodates the communication station.

The design of the communication node in this zone features an ambient interface that is aimed to be integrated in the environment rather than being obvious artifacts. Two large buttons of 30 cm diameter are placed on the sandy ground in between the four trees. They are surrounded by 10 blue LEDs for light feedback. About 2.5 m above these buttons, two rings that are equipped with blue LEDs that give the same light feedback as the corresponding button are hanging in the air between the trees (fig. 7).

Figure 7.: Two large buttons on the ground and a ring above each button form a communication station between four trees

The microphone and speakers for the communication are placed in between the two rings and face downwards on the communication buttons.

The buttons are designed to afford standing and placing heavy objects, such as rocks, on top. They use three pressure sensitive resistors each to sense weight that is applied to them. If the pressure exceeds a certain predefined threshold, the button is pushed. To avoid too frequent state changes and thus opening and closing the communication channel too often, a state change can not be triggered within a time frame of 500 ms after the previous one. This stabilizes the interface significantly and allows children to move and even jump on the buttons without accidentally interrupting the communication. Additionally, the buttons feature physical feedback that is implemented using flexible, springy foam that is placed in between the wooden layers of the buttons.

The Arduino and Raspberry Pi that manage the interaction are placed in a separate box that is connected to the two buttons via UTP cables and also to speakers, microphone and LEDs in the rings.

In this zone, the tube is also modular, comprising two rainwater gutters of two meters length each and one wooden module with added interactivity that is made in a similar way as the tube in the mountain zone and about

1.5 m long (fig. 8). Also, the sensors are the same as in the previous tube, just the feedback matches the water theme. The electronics are again placed in a special compartment being wrapped around the tube. The speakers inside this compartment play both the ambient and the action sounds of the tube. These sounds are not very present at the communication station, since the tube is placed about 10 m from the four big trees.

The wooden tube is placed on stairs inside the water canal. The other two modules, metal rainwater gutters that lead into the tube, expose the material that will fall into the interactive part. These gutters are mounted to wooden poles standing in the same area. An LED strip mounted on top of the interactive tube indicates movements of objects falling through with the help of an animation.

Figure 8.: The tube in the water zone is placed on stairs inside the water canal. Two rain gutters mounted to wooden poles feed the tube.

The soundscape in this zone follows a water theme. The ambient sound that depends on the activity level of the tube reaches from a small stream to an effervescing waterfall. The other tube sounds are influenced by this theme as well, being easily distinguishable from the mountain theme: A water dropping sound, flushing water and a rock plunging into water are the sounds that are triggered by the infrared sensor, the water sensor and the vibration sensor of the tube respectively.

The predominant color for the light feedback in this zone is blue. However, the LED strip animating objects traveling through the tube give light feedback in three different colors—red, green and blue—depending on which sensor detected the object—similarly as for the sound feedback.

3.2.3 *The Portable Zone*

Both artifacts in this "zone" are portable and can thus be placed in any desired position of the play environment. Therefore, the theme of this zone is not predefined either but can be adapted: Dials mounted to both prototypes serve as theme selectors. Both light and sound feedback can thus follow dif-

ferent themes here, resembled by different colors and different sounds. The portability of the artifacts is afforded by the relatively low weight and by mounting handles to the sides: The communication box has two handles, one on each side panel, the tube has a total of four, two on each side.

The tube is made of lighter and thinner wood than its stationary siblings and has an RGB LED strip on top to animate objects falling through the tube. It is about 1 m long, features the same sensors as the other tubes and has a wooden box attached to its downside (fig. 9). This box contains all necessary electronics: An Arduino, a Raspberry Pi, a small speaker, a 12.000 mAh USB battery pack to power the Raspberry Pi and the speaker as well as a 9 V battery to power the LED strip. Thus, the tube is independent from external power supply during the time of its use.

Figure 9.: The portable tube has handles on its side, an LED strip on top and a box containing all electronics on the bottom.

The communication box is a light shoebox-sized wooden box (fig. 10). It is wirelessly connected to the other communication nodes and equipped with the same communication buttons as the station on the mountain that are again surrounded by feedback RGB LEDs. Ambient light is shining from the inside of the box, being visible through a number of holes surrounding its base. This light is emitted by an RGB LED strip that fits the mentioned holes. The box further contains an Arduino, a Raspberry Pi, a microphone, a small speaker, a 9 V battery to power the LED strip as well as a 12.000 mAh USB battery pack that supplies the Raspberry Pi and the speaker with power.

The themes of the portable zone include the two stationary themes—water and mountain—and further feature a space ship theme, a farm and a jungle theme. The color of the light feedback corresponds with each theme in a similar way as in the water and mountain themes.

The portable theme is a means of participatory design that allows children to place the artifacts in their desired positions in the play environment and could thus give insights on the placement of the prototypes for further design iterations that might aim for static contexts and themes again.

Figure 10.: The mobile communication box comprises microphone, speaker, a theme dial and two communication buttons

3.2.4 *Technical Design*

The combination of Arduino and Raspberry Pi as technical platforms for the prototypes enabled us to prototype quickly, work distributedly and get a sufficiently reliable system running. Technically, it would be possible to solely rely on Raspberry Pi, but the ease of Prototyping with Arduino and its great documentation made the distribution into interface (Ardunio) and back-end (Raspberry Pi) the better choice.

The Arduinos are controlling the interactivity of both the communication stations and the tubes. They read out sensor values, directly control the light feedback and, via a Raspberry Pi, also the sound. All LED strips need to be powered separately through 9 V batteries or power adapters respectively, but Arduino provides sufficient power for single LEDs. Each play object, be it a communication node or a tube, has its own Arduino. Each Arduino is connected to a Raspberry Pi via USB. This connection is used to power the Arduino and for serial communication with the Raspberry Pis.

The Raspberry Pis serve two purposes. First, they are responsible for everything related to sound, as high quality audio streaming and playback exceeds the capabilities of Arduino. Second, the Raspberry Pis also serve as the back-end for the communication and manage all data traffic necessary for live audio streaming. The Raspberry Pis run the *Raspbian* operating system, the implementation of the back-end is done in *Python* using version 3.0. Each of the two concepts has its own back-end running on the corresponding Raspberry Pis.

For the tube, the Raspberry Pi serves as an audio player that is being controlled by the Arduino sending simple commands through the serial connection when audio playback is needed. For each playback, the command line audio player *soxplayer* is being called for playing back the sound files.

For the communication concept, the back-end is the channel to the other communication stations. A message triggering the communication is sent from an Arduino to the corresponding Raspberry Pi. This Raspberry Pi then

broadcasts the message in the local area network all communication nodes are connected to. Additionally, it opens up a 64K MP2 RTP audio stream using the application *avconv*. This stream contains the live data which the microphone connected to this Raspberry Pi records. The broadcasted message contains sender and receiver of the respective action, e.g. establishing communication from node 1 to node 2. All Raspberry Pis receive and interpret the message, but only the Raspberry Pi at the station being called forwards it to its Arduino via the serial connection to enable light feedback. This Raspberry Pi then also plays back the respective sound feedback (using *omxplayer*) and opens the audio stream from the other station for playback (using *avplay*).

The Raspberry Pis (an example is shown in fig. 11) at the communication nodes are connected wired or wirelessly to the LAN. Also, the Raspberry Pis in the tubes connected to the network which enabled us to program them without having to physically access them. The network router was placed on top of the hill, underneath the communication station with the funnel. This ensured maximal coverage of the wireless LAN.

Figure 11.: A Raspberry Pi that got damaged during our final evaluation

4

DESIGN PROCESS

The prototypes for our final evaluation were the result of an iterative design process. This chapter lines out this design process and discusses relevant design decisions and methods used throughout the process.

4.1 DIVISION OF WORK

The entire design process was carried out mainly by the two master's students that worked within the project. The project partners from industry and academia supported the work throughout the entire process. Each partner contributed with their special expertise: The landscape architects brought in their knowledge about landscaping and playground design, the playground manufacturer their ideas and facilities for producing playground equipment, the partners from academia contributed with their knowledge in play and in carrying out user studies and the IT consultancy company was mainly responsible for developing the back-end of the communication system.

Despite all help from the project partners, the relevant design decisions were then taken by the two master's students. Each of them had their respective points of focus, coming from the topics of their theses: The interplay between play, technology and the environment for this work and long-term engagement in interactive playgrounds for the other thesis [1]. The work was distributed evenly, though not clearly separated between the two. All critical questions and decisions were discussed together, the main steps carried out together. However, the work was not a co-creation in the sense of *Extreme Programming* [47]. The two students worked individually on smaller steps after adjusting the general ideas. Here, the other student focused more on the development of the tube concept whereas I had my point of focus on the different interfaces for the communication system. Generally, I took a more conceptual focus and was more involved in ideation and refining the concepts whereas the other student did more of the early low-fidelity prototyping. Together, we organized the workshop weeks, interviewed the project partners, planned and carried out the evaluations, visited and rated playgrounds and school yards and assembled the prototypes for the final evaluation.

4.2 INDOOR PROTOTYPING

The prototyping was executed in three workshop weeks with the different project partners. During initial discussions, we made the concepts more concrete, experimented with different sensors and form factors for the tube and different setups for the communication. As a result, we decided to implement different ways of interacting with the communication. Instead of

narrowing it down to one interaction concept, we decided to keep different interfaces with different affordances that would stimulate different kinds of play and also support the learnability of the communication concept. Figure 12 shows an early prototype of one interface for the communication system. Furthermore, we decided to use multiple types of sensors for the tube instead of relying on just one. We experimented with sensors ranging from ultrasound distance meters to motion detectors. Later, we decided to use a combination of an infrared light barrier, a water sensor and a piezo disc for the tube. The advantage of this combination over using just one type of sensor lies in enabling more diverse play since these different sensors react to different materials. Contrastingly, only one type of sensor would lead to a more consistent, predictable behavior of the tube.

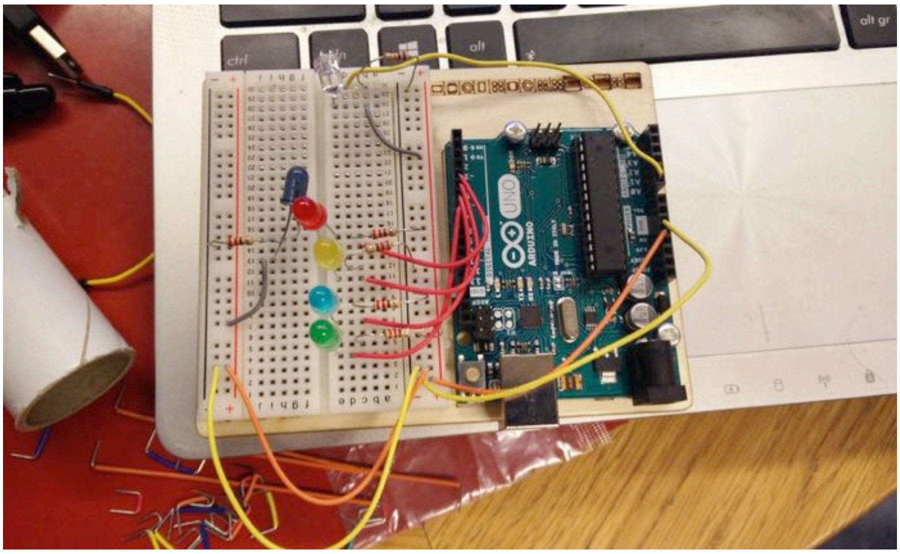

Figure 12.: Early prototype of the interface of the communication system

4.3 intermediate evaluation

In a first intermediate evaluation, we found out about usability and playability flaws and strengths of our prototypes and thus adapted them where necessary. This evaluation, its methodology and results will be further discussed in chapter 5. Subsequent to this evaluation we changed the tube from a rule-based game to a more open-ended version, made its opening a little narrower in order to prevent too large objects to get stuck in the tube and adapted the interaction concept of the communication from a telephone-like protocol to the aforementioned hybrid version between telephone and walkie-talkie. More on these decisions can be found in section 5.5.

4.4 building at a playground factory

Before each of the two evaluation phases, the prototypes were converted into sturdier versions at the factory of the playgrounds manufacturer HAGS (fig. 13). Here, we decided the exact shapes and materials for the prototypes. Both communication and tube concept were implemented using wood as the predominant material, mainly due to the ease of working with it.

The physical shape of the tube has been iterated many times. Coming from a miniature round cardboard version as a very first prototype, we then went to a square cross section. The final solution for the prototypes is a square tube made of wood. This is mainly due the simplicity of its assembly and especially the attachment of sensors to the tube. For future work, tubes with a round cross section would be favorable due to aesthetics and lower risk for material to get stuck.

Although the production of round buttons turned out to be significantly harder than square or rectangular ones, we decided to keep the initial idea of building round buttons for two different reasons. First, round buttons are equally accessible from every side, without having sharp edges pointing at the users. As we wanted to incorporate large versions of the buttons in the ground, this becomes very apparent: The button has no orientation and has to be equally accessible from each side to provide consistent usability. The second reason is that literature suggests to use rounded buttons since they are being perceived as more friendly than ones with sharp vertices [48].

Figure 13.: Building at the factory of the playground manufacturer HAGS

4.5 playground visits

As a source for inspiration throughout the entire design process and also to find a sufficient location for our final outdoors evaluation, we visited numerous playgrounds and school yards in Stockholm and Jönköping. We paid special attention to good playground design in general and good use of landscape in particular. One elementary school in the south of Stockholm then fulfilled the set criteria perfectly: A large school yard in the direct vicinity of a forest with different zones, featuring a water canal through the yard and a climbable rock at its edge. The features of this school yard also had an impact on design decisions taken for the final version of the prototypes and especially the zoning of the play environment.

4.6 SCALE MODEL AND PROTOTYPING IN THE LANDSCAPE

Building a scale model of the entire play environment led to valuable insights on the environment as a whole but did not lead to significant design decisions. Before setting up the environment for final evaluation, we transferred this scale model to full scale and prototyped directly in and with the landscape of the Japanese Garden at KTH (fig. 14). Here, we first examined the interplay of the prototypes with the landscape and the built environment and did one more iteration on our prototypes, which included the extension of the tube with rain gutters.

Figure 14.: Outdoor prototyping enabled us to first explore the interplay of the prototypes and the environment

4.7 FINAL EVALUATION

During the final evaluation, we still made some smaller changes to the design. Only here, we decided to use sound feedback for the communication nodes that actually created a metaphor of starting and stopping communication. Initially, we had employed sounds of animal calls matching the respective themes of the different stations. However, these sounds were lacking obvious connection to the communication and thus children perceived the communication and the feedback as two separate concepts. Also, the final position of the speakers in the water zone hanging between the rings was found only after two days of evaluation, since we observed children frequently speaking directly to the box we initially placed the speakers in. The final evaluation will be discussed in all its details in chapter 6.

5

STUDY 1: INTERMEDIATE EVALUATION

The purpose of this study was to find out about general usability and playability flaws as well as strengths of the prototypes and the underlying concepts. Based on its results, we refined the prototypes for the second study.

5.1 SETUP

The evaluation was held in a lab setting with three communication nodes and one tube installed in different places of the room. The lab was further decorated with large sheets of fabric hanging from the ceiling, laying on the ground and covering hammock stands. This decoration simulated a landscape, divided the room into different zones and created a pleasant atmosphere in the lab. We also collected natural material, such as leaves, branches, twigs and stones and placed it in the room (see figure 15). Additional to the natural material, children got access to a container with water, later also to tap water.

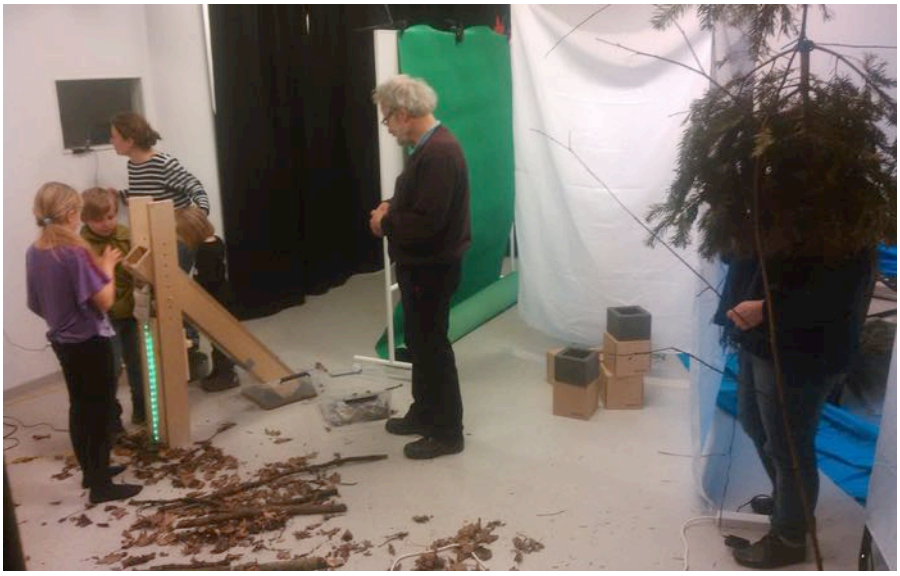

Figure 15.: For the first evaluation, we placed an intermediate version of our prototypes in a lab that was decorated with large fabric sheets and natural material.

An intermediate prototype of the tube was placed easily accessible in a central position. It was about 1.2 m long and featured a little acrylic window, placed about 40 cm below the top of the tube, that enabled children to see objects on their way down the tube. The upper end of the tube rested on a

stand that was equipped with an RGB LED strip that would give light feedback. Sound feedback was being played back through a laptop computer. The feedback worked slightly different than in the final design: Instead of reflecting actions and activity level, the tube got "filled up" over time, reflected by the LED strip lighting up more and more LEDs towards its top. Eventually, the tube then reached a "full" state which was indicated with a winning *ka-ching* sound being played back and the LED strip blinking over its entire length. Throwing objects through the tube triggered playback of different sounds—similar to the final design.

The communication system was based on a telephone metaphor here: In order to establish communication, both partners had to push and hold the corresponding buttons at their stations.

One communication station with one of the large floor buttons was placed in the direct vicinity of the tube. This button had essentially the same design as the ones used for the final evaluation, except that it lacked the waterproof cover. The microphone at this station was mounted to the wall, the speakers stood on the ground.

Another communication node was mounted to a chair that was equipped with two hand-sized buttons on its seat and LEDs for feedback on the back rest. The speakers were hidden under the seat, the microphone was taped to the back rest and the entire chair was wrapped with a sheet of fabrics and a piece of cardboard to hide the electronic parts.

The third communication station with the speaking funnel was placed in a neighboring room close to the seating area of the parents. It featured a button panel placed in a vertical position to the right side of the funnel instead of horizontally in front of it as in the final design.

5.2 PARTICIPANTS

Eight children participated in this study, two of them male, six female. Six of the participants were in our target age group of 6–11 years, the other two were slightly younger. The session lasted for two hours in total, but the participants were able to walk in or leave at any point.

The parents of the participants had to sign a consent form that allowed the children to participate and us to video record the session and take photos and use these media later on in the project.

5.3 PROCEDURE

We invited the participants to play freely in the entire lab without explicitly explaining the concepts. However, in the beginning, some stimulation from parents and informal explanation from researchers was necessary for the first participants to start playing. Later on, the children played freely and discovered the different features of the prototypes on their own and showed them to the newly joined participants.

During the entire play session we took notes and also video recorded the session with one mobile video camera. Subsequent to the play session, we conducted unstructured interviews with six of the study participants. In the interviews, we asked about the preferences and experiences of the children with the prototypes. The interviews have been video recorded for further evaluation as well.

5.4 ANALYSIS

As a base for the data analysis we used our observation notes as well as the video recordings. In a group analysis with three researchers, we discussed the observation notes to find the underlying patterns and extracted the most important findings. While watching the video footage, we took *affinity notes* [49]. The content of the affinity notes supported the findings from the observation notes and complemented them in some details, especially coming from the interviews with the participants after the play session when we did not take notes.

5.5 RESULTS

The major findings of this first study directly influenced the further development of the concepts and prototypes. The most notable results will be explained in the following.

STABILITY OF THE PROTOTYPES The overall stability of the prototypes turned out not to be sufficient for a real play situation. Both the tube and the communication did not work in the intended way, although the tube, unlike the communication, was still playable. The sensors in the tube were almost constantly excited and thus triggered sound feedback very frequently. The functionality of the communication system was very unreliable. This was caused by both the interface that was not filtering sensor noise caused by children moving on top of the button and the infrastructure that often crashed due to the high frequency of state changes. The station with the speaking funnel did not work at all and was thus not used by the children, the other two nodes occasionally could successfully set up a connection.

The large floor buttons had not been designed to be waterproof. Thus, the wooden inner part of the buttons got wet, expanded and consequently got stuck inside the button, making the entire prototype unusable. For the final evaluation, we addressed this issue by covering all the gaps through which water could enter the prototype with waterproof tape.

The tube often got clogged when too much and too large material was being put in there. Although play evolved around declogging the tube, the play stopped when the children were not able to remove the stuck material on their own. Thus, we decided to lower this risk by making the entrance hole of the tube a little narrower, so that too big material could not be thrown into the tube.

COMMUNICATION CONCEPT IS TOO HARD TO GRASP Although children were resilient in trying out the communication stations, it became apparent that the telephone metaphor with two active participants holding the respective buttons to be able to talk was too difficult to grasp. Still, the children managed to communicate basic questions, such as "Who is there?", "Where are you?" or "What are you doing?", but no actual longer dialogs could take place. This observation made us change the communication concept to a hybrid solution between telephone and walkie-talkie as described in section 3.1.1.

TUBE CONCEPT IS TOO RULE-BASED Another discovery on conceptual level regarded the tube concept. The metaphor of filling something up and displaying the fill level with a special indication when the highest fill level

was reached resulted in the play being very much focused on reaching this goal. Although we initially assumed this interaction to leave a lot of space for the children to fill with their imagination, we discovered that the children were not developing scenarios around the filling but rather just aimed on hearing the "winning" sound. Since this was not the type of play we intended to stimulate with the prototypes, we removed the "winning" metaphor in the second iteration and introduced the activity level reflected in soundscape and lightscape.

floor buttons afford standing, jumping and placing material on top Despite the drawbacks of the instability and complexity of the communication use case, the concept of the floor buttons turned out to have affordance for children to stand on, jump on and even place material on top (fig. 16). The first attempts of carefully trying to push the button with their hands quickly developed into children standing and even jumping on the button. Later during the play, one participant discovered that heavy material, such as a stone, placed on the button kept the communication channel open, making the communication much easier. Not only the floor button that we designed for this type of interaction, but also the smaller, hand-sized buttons were used in this way.

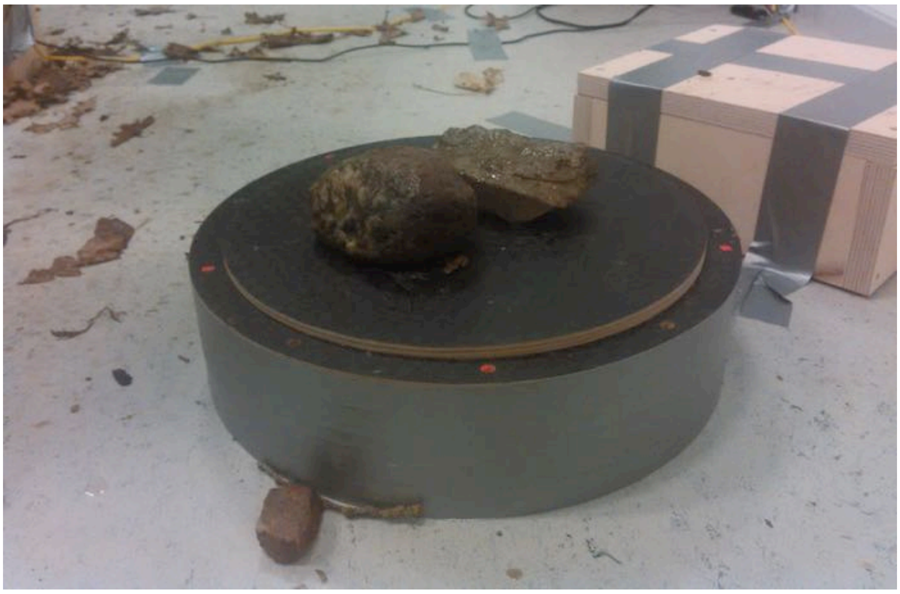

Figure 16.: The large floor buttons afforded children to place material on top

children speak to the voice When children were using the communication prototypes, we discovered that they kept talking to two different points: Many participants focused on the direction of the speakers and talked to the voice coming from there. However, we also observed one participant speaking to a wooden box that was just covering electronics—the microphone was placed in a little higher location. After adults used the same communication station, speaking directly into the microphone, children started to copy this behavior and now also turned their heads towards the microphone while speaking.

aural feedback stimulates play Both the communication and the tube featured light and sound feedback. During the evaluation, we observed the great importance of especially the aural feedback: While two children were playing with the communication prototypes, another participant joined the session and started using the tube—causing sound feedback being played back when objects fell through. This immediately caught the other participants' attention and they decided to switch their play to the tube. The sound feedback remained the most stimulating feature of the tube, keeping children throwing more material into the opening. Even when large stones and branches got stuck in the tube, the children enjoyed the high sound level caused by the constantly excited sensors and kept filling the tube with more material.

Also in the communication, the sound feedback played a central role in the play not only in the actual voice communication, but also in the ringtones and especially the echo of their own voice the participants could hear when using the prototypes. This kept their attention and seemed to make the play with the communication prototypes fun.

water play is popular The material that was used most in combination with the tube was water. All participants seemed to really enjoy to pour water through the opening, observe its flow and listen to the flushing sound triggered by the water sensor (fig. 17). In the interviews after the session, the participants named the tube the "water" play. These observations made us conclude to put special focus on interaction with water in the tube and led to the entire water-themed zone in the final evaluation.

Figure 17.: Intense water play around the tube during the first evaluation

6

STUDY 2: FINAL EVALUATION

The second study was focused on the research question of this thesis: "How do children use the digitally augmented built environment in their play?" We put special focus on how our prototypes influenced the behavior of the children in three ways: What types of play they stimulated, how natural material was used in the play and how the landscape with our prototypes embedded affected the play.

6.1 SETUP

Since the evaluations in related work focus almost entirely on indoor studies of interactive playgrounds (clearly being outdoor environments), we decided to base our evaluation on a study outdoors. Furthermore, it was important to us to not exclusively have our prototypes in the evaluation site but as an addition to an already pleasant playground. Thereby, we aimed to create a more realistic setting as in a study exclusively focused on play with our prototypes. Additionally, we wanted to conduct the study in multiple play sessions to both let the novelty of the prototypes wear off and to be able to see effects over the longer term. Therefore, the prototypes had to fulfill the requirements needed to withstand a longer time outdoors, braving the elements during Swedish spring.

In this study, we used the final version of the prototypes as described in chapter 3. These include three different versions of both concepts that were matched to the different zones of the evaluation location: The school yard of an elementary school south of Stockholm, shown in figure 18.

Figure 18.: The final evaluation with our prototypes was held at a school yard of an elementary school south of Stockholm

The evaluation happened in two stages, a pre-study without our prototypes and the actual evaluation of our interactive play environment. With this design, we aimed to see differences between a non-digital play environment and the digital one that we achieved by augmenting the environment with our prototypes.

The pre-study consisted of 3 walkabouts with pupils from the school through the play environment and two observation sessions of play in the school yard without prototypes. Each walkabout lasted approximately 20 minutes and we let the participants guide us through their playground. The walkabouts served as a method to find out about places the children like and dislike in the school yard in its present form and thus influenced the exact positioning of our prototypes. After these walkabouts, we observed play in the school yard during two school breaks of 40 and 60 minutes length. This prototype-free observation gave more insights on the play in the evaluation location and was also a pilot of our observation procedure.

After installing the prototypes in the school yard, we observed play during four school days with three breaks each, lasting 20, 40 and 60 minutes. On the last evaluation day we did not observe the afternoon break anymore, resulting in observations from 11 breaks in total.

6.2 participants

In the walkabouts, we had three groups of four children each. The children were all from one class and thus knew each other beforehand. We had 9 female and three male participants between 9 and 10 years of age that were randomly selected by the teacher from the set of children the parents of which signed the required consent forms. These forms allowed the children to participate in the study and us to audio record the sessions and to take photographs.

The observation sessions were held in the regular school breaks and thus we had no influence on who exactly participated. However, usually about 240 children from grade one to six—between 6 and 12 years old—were playing in the school yard. This setup fit well to our target group of 6-to-11-year-olds. For the observation, the school did not require us to get consent from all the participants but allowed us to take notes and photographs that later were approved by the vice dean of the school.

6.3 procedure

In the walkabouts, the participants got the task to show and explain their most and least favorite places in the school yard. The children then marked these places with stickers on a map of the school yard. Furthermore, we let them explain how they play in their favorite places and put special attention on the use of the zones with the interesting landscape features—water and mountain. Three researchers accompanied each walkabout: One who interacted with the children, one who took notes on the same A3 paper map on which the children also marked their spots and one who audio recorded the entire session and took photos. The questions asked during all of the walkabout sessions can be found in appendix A.

The observation sessions were not guided in any way—children just spent their school breaks in the school yard as they normally would. In both the pilot as well as the actual observation sessions, we used A3 paper maps of the school yard for taking our observation notes: Whenever an interest-

ing interaction, a special play event or anything else notable happened, we annotated this in the respective location on a map, labeled also with the approximate duration, number, age group and gender of the involved children. The map, as shown in appendix B, also included short descriptions of our main points of interest during the observation. These were set to the following three questions:

1. What type of play happens in the school yard?
2. How does the landscape with our prototypes affect the play?
3. How is natural material used in the play?

This method enabled us to see movement patterns of the children as well as to extract interesting points in the school yard. Based on the maps we could see, where play happens. Furthermore, we aimed to see relations between the position and the play that happened, thus understanding more about the influence of the environment on the play.

6.4 analysis

The data from the pre-study were used to fine-tune the placement of our prototypes in the environment. The zoning of the school yard influenced the planned placement already before the evaluation while the exact positions were discussed after having seen the children playing in the school yard. Furthermore, some minor adjustments to the observation protocol were made after the pilot observation, such as the exact annotations for each note taken.

After the observation week, two researchers analyzed the notes from walkabouts and observations. The maps with the notes were put up on the walls of a lab (fig. 19).

Chronologically, we went through the data, noted down types of play for each prototype and formed emerging observation categories to extract the

Figure 19.: All the maps with observation notes were put up on the walls of a lab for analysis, here showing just a small subset

underlying patterns. This method was based on *content analysis* [50]. In a second chronological iteration over the observation data, we counted the number of interactions with each prototype, based on amount and content of the notes. In a third round, one researcher analyzed the data now based on their location in order to gain more insights on location specifics. In this iteration, the rough number of how often which location stimulated which type of play was counted and (natural) materials used in combination with the prototypes were noted down.

The play was here classified according the five types of play as described by Frost [30]: *functional play* or exercise play that is focused on motor play and body development, *constructive play* or construction play that involves the exploration of material and is focused on creating something or at least involves a specific goal, *symbolic play* that involves make-believe where children pretend absent objects to be there, *sociodramatic play* where children take a role and engage with other children, and *games with rules* where children interact with their peers in a defined context and set of rules [30]. We also analyzed the data with respect to the three stages of play as described by de Valk et al.: *invitation* when the prop invites the child to play, *exploration* when the child explores the interface and *immersion* when the child plays freely and can reach a *flow* state [16].

6.5 RESULTS

The two phases of the second evaluation showed the different use of a play environment without and with digital augmentation. We learned about the types of play that happened and about its relation to the environment.

WALKABOUTS AND PROTOTYPE-FREE OBSERVATION

The first phase, the walkabouts and the observation of two school breaks, led to insights about the use of the school yard. We found out about favorite places of the children, shown in figure 20, places they did not like so much and things they would like to improve. Three favorite places stuck out in the walkabouts.

Figure 20.: A map of the school yard showing all the favorite spots named by children during our walkabouts

The first important space was the conventional playground area with climbing gear, swings and such, that 6 girls named as their favorite spot (fig. 21, left). They described the types of (mainly rule-based) games they played in this area, named the physical activities they liked to do here, such as climbing and jumping and mentioned the important factor, that always lots of friends are around in this area.

Another very important point was the forest, mentioned as their favorite spot by two children, included by another one that liked a particular spot with a view on a rock in the forest and mentioned by one more child who liked it especially during winter time (fig. 21, middle). The children liked the forest for its silent and nice atmosphere with less people than in other areas and the possibility to run freely as much as desired. Also, the opportunity to construct things, especially in winter time, was appreciated.

The third most important spot was the football ground that two boys had as their favorite (fig. 21, right). They were not only playing football matches there, but also football games with different rules that also included a wall next to the football ground in the play. The rules of these games were, as many games we heard about, inherited from older children without the children being aware of the exact origins.

Figure 21.: The favorite spots of the children from our walkabout were the playground area, the forest and the football ground

The remaining favorite spot was a group of sculptures in the direct neighborhood of the school building that was liked for the opportunities to jump and run on and around these sculptures (fig. 22). The children explained and showed a rule-based game that evolved around the sculptures. The rules of this game have been inherited from older children. Here, the built environment—in this case the particular artwork not actually made for this type of play—played a crucial role in the play.

Figure 22.: A group of sculptures in the school yard around which a rule-based game evolved

Interestingly, it was much harder for the children to decide on the places they did not like in the school yard. Mostly, they then complained about the absence of things: One point that the children in all three groups of the walkabout complained about was the plan of the municipality to cut down a part of the forest and use it as building land for new residential buildings. Other than that, multiple children missed a large spinning top because its spinning functionality got disabled (fig. 23).

Figure 23.: The children complained most about the plans to cut down parts of the forest and a large spinning top that did not spin anymore

The two observation sessions in the prototype-free school yard told us about the play types that happened in the three different zones of the outdoor area of the school: The school yard itself, directly adjacent to the school and equipped with table tennis tables, benches, tables, some sculptures, a floorball ground and the water canal going through, the playground area with climbing gear, swings, and slides, as well as the nature zone with the mountain and forest of different densities.

We observed all different kinds of play in the school yard, reaching from purely functional play to sociodramatic play as described by Frost [30]. Following the classification of play types by Frost, we could see a difference mainly between the man-made areas and the natural one: Functional and rule-based play happened mostly in the school yard and playground area whereas the nature was used for constructive, symbolic and sociodramatic play. The activities in the school yard were closely linked to the available facilities: We observed children playing rule-based sports games, such as floor ball, football, basketball and different rope games. Other than that, we saw children running, biking, jumping in the school yard, often in large groups. Similar activities were present in the playground area.

Additionally, the play equipment in this area was used very frequently in its intended use for climbing, swinging, sliding etc. but also as a space to just hang out and chat with friends. Especially on the (rather large) slide this was notable: The slide was frequently populated by many children sitting at its top and occasionally going down in groups.

Contrastingly, in the nature zone we observed completely different play types. Of course, physical activity like running, jumping and climbing was also involved in this zone, but not for its own sake in this case: Children were running, climbing or jumping with a destination, though still challenging themselves, for instance running up at the steepest part of the mountain. The play that happened in this zone was more constructive, symbolic and sociodramatic, in Frost's classification. We found multiple dens in the forest built by children, we heard stories about the restaurant in one of these huts or about a coin children found that they used in a game where it symbol-

ized a larger amount of money. We saw solitary play and group play, we observed children collecting natural material and bringing them "home" to their dens and saw other youngsters sitting and chatting while enjoying the view in particular spots on the mountain.

One artifact we found in a den in the forest was particularly interesting to us: The children used a rainwater tube as a "waste chute", as they called it (fig. 24). The interactions we observed with this particular artifact were threefold: Children used it to throw natural material through, to talk through it and to look through—the same interactions we could observe later at our tube prototypes.

Figure 24.: A den in the school yard featured a rainwater tube similar to our tube prototypes titled as a "waste chute" by the children

OBSERVATION WITH PROTOTYPES

During the four days of observation we were lucky enough to be confronted only with light rain and otherwise mostly sunny weather. This was helpful in the data gathering process but the lack of rain prevented interaction opportunities with the water canal in the school yard that was dried out completely.

The results from the second phase of the final evaluation generally underlined the findings of the intermediate study: We could see the prototypes being used in similar ways, we made the same positive experience with the use of water and were again pointed towards aural feedback being a very good stimulus for play. One difference was notable, though: Children were not careful and inhibited with the prototypes as in the first evaluation, but played freely in "their" play environment. More importantly, we now found out about the impact that the digitally augmented built environment has on play: We could observe changes in the types of play that happened, in the use of space and in the use of material. These changes will be discussed in the following sections.

6.5.1 *Types of Play*

This section describes how children used the prototypes in their play and how the types of play changed with respect to the prototype-free setting. This difference is interesting, since it describes very well how the digital artifacts impacted the play. However, also the different concepts and even the different prototypes within one concept stimulated different play types, different play patterns, different play scenarios. Thus, the play that happened at each of the prototypes will be discussed separately.

Tube Concept

The tube prototypes were successful in stimulating play mostly until the exploration phase. Although the play sometimes sustained for up to 20 minutes, it did not very often show the classical characteristics of the immersion phase—no rules became apparent, no stories evolved around the play. However, the immersion phase was reached even without exposing these typical characteristics. We could see experiments with all kinds of materials, including natural material, toys and body parts. The dominant feedback modality was sound, though it was influencing the play very differently in the different prototypes. In comparison to the communication use case, we saw more problem-solving games around the tubes, more functional play, constructive play and even games with rules.

MOUNTAIN TUBE The long tube in the mountain zone succeeded best in stimulating its intended use: Children were tossing in all different kinds of natural materials, including stones, twigs, large branches, and pine cones. Additionally, we observed instances of toys like stuffed animals and tennis balls being casted through the tube. However, the tube was also being used in different ways: Children were sliding down on its surface, using it as a speaking tube, were simply looking through or hit the outside of the tube to stimulate the sounds. We also saw children putting their arms or legs into the tube, one boy even lost his shoe while doing so.

One significant play pattern around the mountain tube was the distributed play at upper and lower end of the tube: One or more children were putting in objects at the top, another child or group of children was at the bottom to return the material after it reached the lower end of the tube (fig. 25 a). This was often accompanied by one child at the lower end looking up the tube while objects were going through and taking away their head only in the very last moment before the object would hit it. Here, children explored the physical properties of tube and material in a very direct and bodily manner.

Another stereotypical interaction with the mountain tube was the communal declogging of the tube after large objects got stuck in the tube on their way down (fig. 25 b). This took up a large share of the play time around the mountain tube and was a highly cooperative activity. Children used large branches of two to three meters length to poke inside the tube and get stuck objects out. They were planning and coordinating their actions ("If we throw in three stones at once, it will come out") to achieve the common goal of getting the tube free again.

The ambient soundscape produced by the activity level also, at few occasions, caught the apparent interest of children. One interesting scenario we observed involved the raising intensity of the soundscape in the play: A group of boys was playing next to (but not with) the tube. As the activities with the tube increased, the weather condition reflected by the soundscape

changed from rain to thunderstorm. Subsequently, one of the boys in the group besides the tube said: "Load the cannons, it starts to thunder and rain!" This is one of the few instances we saw the prototypes being used as material for imaginative play. However, the soundscape also carried value in itself: Sometimes children, mostly girls, were sitting under the speakers and listening to the bird calls, the changing weather conditions, the rain and storm. This, however, did not obviously impact their play or their behavior, though it might have had an influence on the perception of this particular zone as well as on the emotional state of the child.

The general level of activity at the mountain tube was—in comparison to the other tubes—rather continuous, though less interactions happened with it in the later days of the observation phase. The play types did not change over time. The play remained often in the exploration phase although sometimes also the immersion stage was reached. The observed play types were functional play (sliding down the tube), constructive play (throwing material through) and little sociodramatic play (the war game besides the tube).

(a) Play at the rock tube was often distributed to upper and lower end

(b) Communal declogging of the tube was a recurring play pattern

Figure 25.: Play situations at the rock tube

WATER TUBE At the water tube we could see similar behavior and similar play as around the mountain tube: Natural material casted into the tube, small toys thrown through it and "manual" interaction directly with the tube. However, the physical appearance—the placement in the canal between the stairs and especially the extension of the tube with the two rainwater gutters—changed the play and the materials being used in connection with this tube.

On the first day, the tube was almost only used for water play, since we placed a water hose directly next to it (fig. 26 a). Three notable things happened here: First, the tube prototype itself played a significantly lower role in the water play than the two rainwater gutters. Second, the digital component of the tube prototype was not considered at all by the children. And third, the sheer amount of water finally was too much for the prototype to handle and killed the electronics inside which we subsequently repaired. Here, we could very well see the importance of the physical appearance of the stations as well as the available material around the prototype.

The play changed significantly in the following days when we turned off the water supply: Now, children used different materials to evoke the sounds and lights of the tube. The focus here was on spherical objects, such as tennis balls, marbles or pine cones. Also sand played a role at the water tube, both being thrown through but also to extend the tube itself. The

lower end of the tube was much more easily accessible than the upper end, where the end of one rainwater gutter was fed into its opening. A group of boys then extended the tube with a sand track that went down the stairs the tube was resting on (fig. 26 b). One interesting game evolved around this (physical) property of the tube: The boys let tennis balls roll down the tube with the goal to reach a certain spot in the end of the sand track. They kept trying where to place the balls in the rainwater gutter in order to reach that particular point.

The digital capabilities of the tube did not play a role in that game at all, though. The sound feedback was, however, often a stimulus for children to start playing with the tube. This was also verbalized towards us: When the tube was unplugged from power supply and did not make any sounds, a girl approached us and asked for the sounds to be on again. After we did so, she started playing at the tube. Also, we heard the following short dialog between two children: "Why are you putting sand in?"—"Because it shall make sound!" This was related to the sounds when objects fell through the tube. These also stimulated children to invite their peers to join playing with the tube. "Listen, it makes sounds...!" The ambient sounds of the tube did not play an obvious role in the play, neither did the light, although a few children were noticing the LEDs flashing and subsequently examined them further without actually incorporating them in their play.

The level of usage at the water tube dropped significantly on day two after we turned off the water supply. Especially during one recess when we additionally took away the rainwater gutters, the tube got almost no attention. Bringing back this physical quality of the tube also brought back the interest of children in the prototype. However, the use remained very low in comparison to the first day. The play patterns we observed here were constructive play (material explorations, extending the tube), symbolic play (using the rain water gutters as tracks for toy cars) and games with rules (e.g. the ball game).

(a) The water tube was used very frequently when the water was running

(b) Children extended the lower end of the tube with sand on the stairs

Figure 26.: Play situations at the water tube

portable tube The portable tube was used in rather different ways than its stationary siblings (fig. 27). Although we could observe a few interactions with materials being thrown through the tube, this was not at all predominant with this prototype. Here, manual use with body parts, slamming the tube on the ground, stirring in it with sticks, talking and looking through it were the most common interactions. For the portable tube, the adaptable sounds were important. Children used the tube as a sound machine to

get their favorite sounds. The adaptability was used a lot, though certain sounds were used significantly more often than others—mostly the sounds that stuck out, such as the *Tarzan* shout and the space ship sounds. These sounds also stimulated play: One group of children started to sing the *Star Wars* theme song when triggering the space ship noises, other children imitated the noises that came from the tube.

The tube showed affordance for being carried around, though the action radius stayed very limited—children did not carry the prototypes too far away and once even picked it up and returned it to us when they found it a bit further out in the forest (where we placed it before to see what play it would stimulate there). Still, one boy claimed: "This one I'll take to my hut." But he never did so and just continued using the tube around the places we put it in the beginning of each recess time.

One interesting game scenario evolved around the portable tube. After a child saw the tube (*invitation*), it was talking to one of the recess hosts of the school about what the prototypes are and found out about us being researchers in the school yard. Then, this child started to explore the interaction possibilities with the tube (*exploration*) and consequently turned into a researcher itself, using the tube as a research instrument (*immersion*).

The usage of the tube dropped on the third day after its novelty was gone, though two boys were returning to the mobile tube almost every break to play with their favorite sounds. The play patterns here reached from functional (slamming, stirring) to symbolic (using as space gun) and sociodramatic play (the researcher).

Figure 27.: Play situations with the portable tube

Communication Concept

The back-end of the communication concept had significant technical difficulties in the beginning of the observation week that made communication almost impossible. We continuously improved the prototypes throughout the entire week and got the communication working on day 2 and somewhat stable on days 3 and 4. However, the prototypes never reached a totally reliable state where communication would be flawlessly possible. Thus, the significance of the data in relation to this particular concept is questionable, while we still could observe interesting play and draw conclusions on play with digitally augmented play environments, since the actual interface with light and sound feedback worked more reliably.

Very often, we got to the establishing state of communication: Children shouting "Hi! Can you hear me?" or "Who are you? What are you doing?" were observed very frequently. When there was nobody available or willing to answer the "call", we observed solitary children getting frustrated quickly and leaving the station. If they played at the communication stations in groups, they were more resilient in trying and sometimes did not even care if someone would listen, but just performed a monologue or sang a song. The few instances of actual dialogs through the communication system were mostly related to coordination of the communication itself. "Can you hear me down there?"—"Yes. Wait, I'm coming up!"

One common misconception was that the communication was just one-way from the mountain to the water station. Children pointed that out by saying things like "I also want to speak—I'll go up to the mountain". This might be due the different affordances of the different stations but also because of the technical difficulties with the communication. The sound quality was also often poor, because children were shouting directly into the microphones and thus caused lots of feedback noise. Subsequently, the system was considered to enable "sound" rather than communication. These misconceptions decreased when the communication worked better both ways. The communication concept with its three very different nodes evoked very different types of play—though most of them were not actually related to the communication. We saw functional play, symbolic play, sociodramatic play and games with rules. The play went through all three stages of de Valk's *Stage of Play* model, when the communication actually worked, when children pretended the communication to work, or when they played with the interface in no relation to the communication.

ROCK COMMUNICATION The communication station with the funnel on top of the mountain fulfilled our expectations to be an inviting interface for communication. Already on day one, when the communication did not work at all, the affordance of the funnel invited children to speak into it and to sing (fig. 28 a). It had such affordances also for listening—many children were holding their ears against the funnel. These play patterns were also continued throughout the entire week, also when the communication was working. Giving speeches ("Dear fellow citizens...") was part of the performative play in this very stage-like zone on top of the mountain just as much as singing in large groups (fig. 28 b) and using the funnel for stadium announcements. The funnel as a physical artifact was popular to such an extent that sometimes small fights for the place at the funnel were fought.

(a) The funnel proved its affordance for speaking

(b) A group of children performs a song to the funnel

Figure 28.: Play situations at the mountain communication station

The buttons on the table underneath the funnel were not always used in connection with the communication. Besides their intended use we observed other usage, especially in the beginning of the evaluation: Then the feedback on button pushes was still mountain animal sounds that were a great stimulus for children to push the buttons over and over again. When these sounds were replaced with a more communication-like *da-ding* sound in the beginning of day three, this behavior stopped. Still, the buttons were used as a percussion instrument every now and then.

The interface was not always being used in its intended way: Children were speaking to the funnel without pushing the buttons, they were pushing the buttons without speaking or repeatedly pushed over and over again while speaking. In the end of the observation phase, we could see children explaining the interface to their peers, including the meaning of the two different buttons and their respective communication partners.

The play at this zone was highly performative (singing, speeches), the communication evoked symbolic play (when children pretended it to work) as well as sociodramatic play (stadium announcements). The usage of the station stayed rather stable throughout the entire week, though a decrease in use could be observed on the last day. Children went through all three phases of play, though again the exploration phase was continued for a very long time.

WATER COMMUNICATION Before the actual communication worked, the buttons were already used very frequently: To jump on, to stand on, to sit on, to see the lights in the hoops flashing, to hear the sound feedback (fig. 29). Children often incorporated the physical properties of the buttons in their play. Also, the two buttons being placed next to each other stimulated children to do synchronized activities on both buttons: Jumping at the same time, playing air guitar together or switching positions from one button to the other at the same time. Also, the buttons had a certain performative affordance: We could see a child doing a little rap performance on one of the buttons as well as the mentioned air guitar play.

Figure 29.: Play situations without communication by the water station

The connection between the buttons and the communication was not clear to many children—especially in the beginning of the evaluation. The buttons were seen as a “sound machine” that would make funny animal sounds and turn the light on when stepping on them. Also later in the week with a

working communication system, play with the interface happened separate from the communication. We observed one group of children playing on the buttons, thus enabling communication while another group was trying to have actual communication with the other node.

The general appearance of the zone with the rings over the heads of the children made them invent the most interesting stories around its functionality, especially before the communication actually worked. The prototype was said to give a tickling feeling in the tummy, to create hunger, to be able to read thoughts, to be teleporter, a time machine, an "alien thing", and many more. These very imaginative descriptions happened almost only on day one when it was not clear yet that it would be an interface to a communication system. Still, some children observed the logos on the buttons and directly asked if it was a telephone already on this day.

When the communication worked, the interaction in the water zone was characterized mainly by children shouting very intensely (fig. 30). This might have to do with the mentioned technical difficulties that made it hard to understand the actual communication and got better, when the sound level of the speakers in this zone was decreased. Children adapted to the intense loudness of the speakers before and were shouting even louder if the communication did not work as desired. The communication was tried out very frequently, children coordinated themselves and split up between the two stations on the mountain and between the trees and often got excited when it actually worked. However, over time also the communication lost a lot of attention and significantly less children were playing with the prototypes, more besides them. Here, an interesting effect got visible: The communication disrupted play next to the station in two ways: First, during one break, one boy playing in a group of children next to the station always went to answer calls from the mountain. He was just saying "Hi!" and then returned to his previous play, though. The prototypes invited him to play and he used them in the intended way, but he did never actually communicate with the other station. Second, another boy in the same group repeatedly shouted: "Shut up!" with an angry expression in his face, when another child was talking from the mountain station.

Figure 30.: Play situations involving communication at the water station

This communication node evoked the most diverse types of play. We observed all five of Frost's play types, though functional (jumping on buttons), symbolic (teleporter etc.) and sociodramatic play (with the communication) were dominant. The play was focused on exploration but also reached the immersion phase at times.

MOBILE COMMUNICATION The mobile communication box was the least functional but still frequently used prototype. Here, mostly not even the sound feedback worked out, though the light feedback was working stable in all different colors according to the theme chosen with the dial. Still, children were using the communication box in its intended way: They simply acted as if the communication would actually work (fig. 31). Additionally, the communication box was used as a percussion instrument, as a camera and also just to get colorful light feedback. Children were using mostly their hands but also sometimes their feet to operate the buttons, when the box was placed on the ground.

We could observe longer interactions of fewer children with the mobile box than with other prototypes. One boy used the communication box as an announcement station: "To the office!", he commanded repeatedly at different positions. Another boy was using the box for the duration of one entire break. He carried it to different locations in the school yard, tried it out and also did the same thing directly next to the two other communication stations. He was examining exactly how it would work and also tried to report his findings to peers—though those were not interested.

Play types with the mobile communication box were mainly symbolic play (camera play, pretending the communication to work) as well as functional play (hitting the buttons). The play with the mobile box reached the immersion state only with very few children, mostly they stopped after the exploration of the interface.

Figure 31.: Play situation with the mobile communication box

6.5.2 *Use of Space*

Since the focus of this thesis is the relation triangle between children, the technological artifacts and the environment, we observed how children used the physical space of the school yard in a prototype-free environment as well as with the prototypes in order to be able to see a change.

The first and most obvious change in the use of space was that our prototypes—as expected—attracted children to the previously unpopulated areas where they were placed due to the great natural conditions of the zones. Both the communication station in the water zone and the mountain zone as a whole were not very popular before we put our prototypes in the school yard: In the mountain zone we observed children almost only passing through to get to other places, the area of the communication station in the water zone was not being used at all—children were playing only at the barbecue place in its direct vicinity but not in between the four large trees where the station was placed.

After the prototypes were set up, we could see the landscape in the close proximity of the stationary prototypes being used differently than before. Children were running along the tube prototypes, especially the long tube in the mountain zone. The steepness of the part of the mountain the tube was placed at did not prevent the children from doing so. They took on the physical challenge of climbing up and down and followed the material falling down the tube or collected it again from the lower end after it fell through the tube.

The tube in the water zone got integrated with the landscape when children extended its end with sand to shape an even longer track for material to go down. Other than that, we also saw one occurrence of the prototype influencing the way the children used the built environment around the prototype: One boy let a pine cone go down the tube in the water canal and subsequently used a railing next to the tube that was similarly slanted to let another pine cone go down. The prototype apparently changed the way this boy perceived his environment—it made him act differently with the environment he had been playing in for a long time already.

Also, at the communication node in the water zone, we observed different use of the landscape: Not only started children to look towards the sky, caused by the two glowing hoops and the sound feedback above their heads, but also they were integrating the large floor buttons in their physical movements through the school yard: Often, we could see children taking a detour through the communication station in order to run over the large floor buttons.

Another important observation was the landscape usage between the zones—the mountain and the water communication nodes in particular. Many children were now running from one station to the other one in order to try out the communication, thus experiencing the steep cliff in between the two stations. The other prototypes did not stimulate such behavior.

6.5.3 *Use of Material*

The second focus point of our design was the use of natural material in combination with our prototypes. The tube concept was even explicitly focused on affording exploration of different materials and we expected the prototypes to stimulate the use of available natural material around, such as stones, leaves, and twigs. Indeed, the prototypes met this expectation as lots of natural material got thrown through the tubes—at least the stationary ones. Already the process of searching for material seemed fun and children were thus exploring their surroundings and also the behavior of different materials in the tubes.

As opposed to the first evaluation, we found the large floor buttons and the hand buttons of the communication nodes almost not being used in

combination with natural material—only one child tried to put a stone on top of one of the large floor buttons in the water communication station.

6.5.4 *Usability Flaws*

Besides all the mentioned lessons we learned on play and space use, we also could observe a number of flaws in the usability of our final prototypes as described in chapter 3.

The dials of the mobile prototypes did not give any direct feedback when being turned, thus causing confusion among the children if they would actually change something. Playing back a characteristic sound of the respective theme as well as giving light feedback in the respective color on dial turn would easily overcome this problem.

One usability problem with the sound feedback of all prototypes was that the volume was always either too low or too high to be well audible. An adaptation to the sound level in the environment would be advisable here.

The light feedback at all the prototypes played a much less significant role than the sounds. This was not only due to the intruding nature of sound in comparison to light, but also since the light feedback was just not apparent enough for an outdoor environment during daylight. Using stronger light sources than LEDs would help to create meaningful feedback not only with sound but also with light.

Although the usability of the large buttons in the water communication node was good and they afforded their intended use, one recurring observation was the attempt of children to repeatedly jump harder and harder on the buttons—apparently with the intent to change the feedback. This did not happen, since the feedback was always the same regardless of the force applied to the button. It might be interesting to disconnect the communication feedback from the jumping feedback, since the communication channel should stay open even if short jumps would briefly interrupt the button push. The implementation used for the evaluation had a 500 ms timeout that prevented the communication channel from being opened and closed too frequently (a lesson we learned in the first study), though more immediate feedback on leaving the buttons might have been favorable in order to keep children interested in playing with the prototypes—we observed some cases of children jumping on the button, hearing a sound, getting interested, leaving the button again and subsequently also the station, because nothing happened *immediately*.

6.5.5 *Summary*

The play we observed covered all five of Frost's play types. However, we saw our prototypes being used most often in functional and constructive play, but also symbolic and sociodramatic play was often present. Only games with rules did not emerge very often around the prototypes. Although the different physical appearances of the prototypes led to different play in the respective zones, the differences in usage of the prototypes were not only caused directly by the interface, but also by the affordances of the zones themselves. Already before we placed the prototypes in the school yard, we could see tendencies in the usage of the different zones: Functional and rule-based play happened mostly in the man-made structures whereas the nature was used for constructive, symbolic and sociodramatic play. The

prototypes added to the play in the zones but after all did not change it in any other ways.

Regarding de Valk's *Stages of Play* model, we saw play in all three phases, although a focus on the exploration phase was notable. Additionally, the prototypes were great in inviting children to play. The immersion phase was, however, not reached very often. Especially the aural feedback of all prototypes worked as a great stimulus for play. Although also the visual feedback was noticed by many children, it did not elicit any more reactions than to its pure presence. Contrastingly, the sounds caused much stronger reactions. They often made children laugh or discover the prototypes further, but the loud feedback noise at the communication nodes also resulted in children verbally expressing their desire for silence. An explanation for that is that the sheer loudness of the soundscape creates "a general atmosphere of confusion" and leads to stress [51]. However, if applied properly, the sounds stimulated the imagination of children and led to play.

The imagination of children was notably stronger in the beginning of the observation phase, when they were unsure about the purpose and use of especially the communication prototypes. After all, the system with just pure sound and light feedback and no actual purpose was stronger in stimulating imaginative play than the system with working communication. However, a totally reliable communication system would have the potential to be turned into actual *play material* that is used *in* the play rather than *being* the play itself. The barrier to establish communication was so high that successfully communicating was already a game in itself and thus the communication system did not serve as a medium for other play scenarios.

All in all, the prototypes were used quite frequently although a significant decline in use could be observed already during the four days of evaluation. Still, the children accepted the prototypes as part of the inventory of the school yard, showed them to and tried them with their parents and even included them as a "ritual" when passing by: Children were often doing the little detour to the prototypes to jump on one of the large floor buttons or to put one object in one of the stationary tubes when the school bell rang back to the lesson.

7

CONCLUSIONS

The main contribution of this thesis is to examine the influence of the digitally augmented built environment on play. Our findings indicate, that the digital augmentation of the built environment influences the way children perceive the space they are in—through material around, movements between, or gazes stimulated by the artifacts. According to Gibson's theory of affordances [39], the digitally augmented built environment can thus stimulate certain types of behavior, that means certain games, as well as it can change the use of space.

Does that change really come from the digital component or is it inherent to new equipment placed in the landscape and its affordances, i.e. a change of the built environment? The results of our evaluation give an indication for an answer to that question. At the times the prototypes were not functioning or being turned off—i.e. at situations without the digital component—significantly less children were playing with the physical prototypes than in situations with the digital component. However, this could also be just because the functionality was taken away at these times, since it had been there earlier on and the children perceived the prototypes as broken then and did not want to play with them until they got fixed. Still, I argue that the digital component carried value in itself: Although it was not very often, the digital material got also part of some games children played. Additionally, the conversations of children related to the prototypes were mostly focused on its digital component. The communication stations were called "sound machines", the sounds of the tubes invited children to start and continue playing. The attitude of the children towards the prototypes was not "Let's jump on the buttons, it feels so cool!", but rather "Let's jump on the buttons, it makes sounds and lights!". Also, only the *working* communication system stimulated movement between the water station and the mountain—a dormant quality that would not have been discovered without the digital component. Even though the physicality of the prototypes undoubtedly had a large influence on the play, the digital component was being used as a reason for play by the children, it was a very good stimulus for play and did influence the play scenarios as well.

If now the digital component has an influence on play, why should it then be incorporated in the built environment? This question is more difficult to answer. Based on related work in interactive architecture, we expected the digitally augmented built environment to be able influence behavior [37]. The capabilities of soundscape and lightscape as part of the environment [43, 44] substantiated this expectation. However, other related work used loose props in playgrounds to stimulate similar effects: The *Space Explorers* as described by Seitinger are designed to mediate the relation between children and their environment [8]. These artifacts are autonomously moving in the play environment and thus stimulate children to follow them and explore the environment. Similar effects of mediation were visible with

our prototypes—both the portable ones as loose artifacts and the stationary ones that were more part of the environment stimulated children to discover dormant values of their environment. The portable prototypes were carried around in the playground, thus opening up new views on the territory and the stationary prototypes stimulated interaction with the environment in their direct vicinity and in between the zones. The communication station in the water zone, designed to be embedded in the environment, showed no significantly different results in its ability to influence play than the other prototypes. Therefore, it remains unclear if embedding digital technology into the built environment really influences play differently than loose digital props in the playground. From a practical point of view, however, in the context of a public play environment embedding technology is the only feasible way of digital augmentation: Since loose artifacts are likely to get lost, the benefits of digital technology can only be taken advantage of if the technology is incorporated in the play environment.

As a conclusion, the digital augmentation of the built environment can certainly not be seen as a cure-all for better play. Play happens under all circumstances, in both the built and the unbuilt environment. However, the digitally augmented built environment has, similar to digital play props in the environment, the potential to become part of children's play and shows capabilities in *mediating* the relations between children and their environment in a playful way. With the interactivity, we created a *medium* for play that can strengthen the relationships between children and the play environment as described by Seitinger in [8]. Thus, the interactive play environment can in the end mediate rich play in and with the environment.

8 DISCUSSION

One important goal of our design was to be embedded in the built environment and incorporated in the landscape of the play environment. Although our prototypes were *built for* a certain landscape, most of them were not actually *embedded into* this landscape and still remained artifacts placed in the environment. The prototypes should be truly embedded in order to strengthen the connection to the environment and weaken the relation to the researchers: During the evaluation, children were clearly seeing the connection between the observers and the prototypes. They often asked us about the prototypes and our activities. This connection certainly influenced the results of our study, because children were seeing the prototypes not entirely as part of their play environment.

Another main design goal was to support open-ended play with our prototypes which also succeeded to some extent but could still be further improved. Since the decision for the use cases implemented in the prototypes was not part of this thesis work but came from the larger project context, those were not specifically focused on this design goal. Maybe the limited interaction possibilities of the prototypes, that were seen as a quality based on related work (e.g. [7]) after all hindered more diverse open-ended play as suggested by a more recent study: "If the design supports few interaction opportunities, it is difficult for players to come up with diverse game play" [52]. Still, the results could suffice to answer the research question posed in the beginning of this thesis and draw conclusions on the interplay between the digitally augmented built environment and play.

The observation protocol for the final evaluation could have been improved in two ways. First, the note-taking should have involved more explicit numbers on duration rather than just explanations of the interactions. This became especially apparent during analysis, when we counted the interactions with the prototypes. Second, backing up the vast amount of qualitative data with some quantitative data would have been helpful. Initially, we planned to let the prototypes log each activity and additionally gather GPS data from the portable prototypes to be able to gain insights on their use in certain contexts. This failed because of a technical error and also because the children were not moving the prototypes as much as we had envisioned it.

Although the digitally augmented built environment showed positive effects in combination with play, the question remains if it is really needed for play and if it is better than any other means of improving a play environment. After the four days of evaluation I have an ambivalent view on this question. On the one hand, the interactive playscape does change play, it does stimulate play and it can mediate play. However, does it really improve play? Probably not. The play in the prototype-free environment was not less diverse, seemed not less fun or less immersive than with the prototypes—maybe even the opposite. Nature has the tendency to cause

comfort and evoke positive emotions. The digital prototypes sometimes lead to discomfort expressed by the children during our observation. Was that just caused by the novelty of the digital component? Did this novelty also cause the positive effects the digital artifacts showed? These questions cannot be answered with the material we have. However, the societal dimension of technology getting more and more part of our everyday live might be an answer to whether we need the digital component or not. Thus, the question is maybe not that much *whether* we should augment the environment digitally but *how* we can do it in such a way that it mediates the relation between child and nature in a playful manner. If the digitally augmented built environment could in the future provide the comfort for children to play next to it, this would be a great contribution to children's play.

9 FUTURE WORK

As future work in the field of interactive play environments, it would be useful to examine one shortcoming that was identified during literature review: The lack of longitudinal studies regarding the long-term engagement of children in interactive play environments. Some indications on this topic are given already in a second master's thesis in the same project context [1], but a study over a longer term would be necessary to validate the findings from this investigation.

Since the environment in which this study was performed was rather ideal in terms of space, landscaping and zoning, it would be interesting to test similar concepts in different environments to see if the digital augmentation shows different effects in these environments. First, a "bad" school yard with poor landscaping could give indications on how the quality of the environment can be changed with digital augmentation. Second, a public playground with more fluctuation might be a good location for a study about how interesting these concepts are in a real public setting without constantly returning children.

One more recommendation for future work comes from an interesting observation during our evaluation. Although we could observe social play and lots of collaboration around the prototypes, we saw some indicators that especially solitary play of less socially active children was supported well by the prototypes. However, the data of this study are not sufficient to prove or disprove this assumption, thus more work would be needed on this topic.

For the prototypes and their further usage in the DigiFys project, the most important pieces of future work are to stabilize the communication system, to make the prototypes durable for longer outdoor use and to really embed them into the environment in order to be able to perform a long-term study about the two concepts.

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Appendices

A

WALKABOUT QUESTIONS

- Which places do you like in the school yard? Why?
- What do you play (there)?
- How was the last time you've been playing there?
  (Explain exactly what you did—no general statements).
- What places don't you like in the school yard? Why?
- Have you always liked / disliked these places or did you have different favourites (/non-favourites) before? (In previous class / when you were younger / starting at school).
- *(if it doesn't pop up):*
  - Do you play on the rock? How? Why / Why not?
  - Do you play with the water? How? Why / Why not?

B

OBSERVATION MAP

Figure 32.: The map used for note-taking during the observation sessions of the final evaluation