interActive Environments: Designing interactions to support active behaviors in urban public space

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Loes van Renswouw

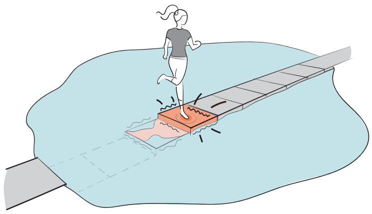

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Table of Contents

1 Introduction

1.1 Physical Inactivity: A Key Challenge in the Pursuit of Healthy Living

1.1.1 Movement Matters

Over the years, technology has provided us with ever increasing levels of comfort in all aspects of life. With motorized transport, mechanized domestic appliances, and home-deliveries, the basic tasks and sustenance needed to live our lives are evermore automated and easy to obtain. This trend has also brought a shift from physical labor to office work for a large part of the workforce. The downside of these developments, however, is a considerable decrease in physical activity for a major part of the population in these modernized societies, resulting in a new array of societal concerns [238,349].

Frequent physical activity is a well-known and key part of maintaining a healthy lifestyle [42,238,334]. An active lifestyle contributes significantly to overall health [159,238] as regular physical activity has extensive benefits for the body, including brain health and even delaying cognitive decline [33]. It contributes significantly to healthier body mass and composition, bone health, cardiorespiratory and muscular fitness, and cognitive function [178]. Additionally, it can contribute to social interactions, that in turn contribute to mental wellbeing and the shaping of behavior. For all these reasons, sedentary behavior and physical inactivity are increasing public health concerns [33,92,134,339].

Physical inactivity is defined as not meeting the present recommendations for physical activity [178,339]. For adults this means at least 150-300 minutes of moderate intensity or 75 minutes of vigorous aerobic physical activity per week, according to the World Health Organization (WHO) guidelines [336]. Therefore, people are considered physically inactive if they do not meet the equivalent of walking for 30 minutes at least 5 days a week [33]. For additional health benefits, longer exercise is encouraged, as are muscle strengthening exercises on at least 2 days a week and limiting time spent sedentary [336]. However, in these guidelines WHO also emphasizes that even when people do not meet the recommendations, doing *some* physical activity will still benefit their health compared to none at all [336].

The scale and impact of physical inactivity worldwide are severe enough for it to be described by some as a pandemic [127,159,257]. It increases the risk of many health conditions, including heart disease, type 2 diabetes, stroke and (certain) cancer(s) but also mental conditions such as depression [178]. It is among the leading causes of death [150,159] and according to Blair (2009), low cardiorespiratory fitness accounts for about 16% of all deaths in both women and men [33]. Next to health benefits, stimulating physical activity brings also social, environmental, safety, and economic benefits [48,229]. This is therefore a vital and timely challenge for researchers, practitioners, and governing agencies [159,257,334].

1.1.2 A Growing Challenge

The importance of physical activity is well-established through research and increasingly advocated through information campaigns on a variety of channels, making it a well-known issue in the general population [33,58,80,127,188,342]. However, this awareness has not (yet) led to the desired increase in physical activity levels, with many people remaining inactive [124,178]. The majority of people are aware of the health risks, but it remains difficult for them to actually embed enough physical activity in their daily routine [190,251] and the COVID-19 pandemic only added further to this issue [127]. This high prevalence of physical inactivity combined with its consequences for individual and public health make it a global health priority. Finding effective ways to encourage people to be more active and helping them to maintain a healthy lifestyle by promoting physical activity is thus a critical endeavor to increase public health [92,159,334,335]

Despite considerable –and increasing– awareness of the importance of being active, many people still struggle with embedding enough physical activity into their everyday routines [251]. A main cause here is their sedentary lifestyles [30]. While time spent sedentary is not spent physically active, it is possible to meet physical activity guidelines while also spending most waking hours involved in sedentary behaviors. Still, sedentary behavior in itself also poses significant health risks [40,92,238]. Inactive means of transportation such as cars and public transport are much more convenient and popular than active alternatives such as walking or biking. For many people, being at work also equals staying –mostly sitting– still, making physical activity a 'leisure time activity'. Even then it is only an option among various leisure time activities that are also sedentary in nature, such as watching a movie or eating out [277]. To optimize comfort, many places are designed to facilitate sedentary behavior, so also our living environment is increasingly planned and designed to further reduce incentives and possibilities to be active [108,117,294].

People also experience barriers to being active. 'Lack of time' is identified by several studies as a main reason for inactivity [30,145,307], making it another 'must' on people's to-do lists [136]. Additional reasons for inactive behavior can be; *physical*, such as an injury; *emotional*, for instance, being shy or embarrassed; *motivational*, like expecting failure; *time*, and *availability,* which includes absence of facilities, funds, equipment or a partner [30]. A study by Salmon et al. (2003) among 1332 participants indicated the 'cost', 'being (too) tired', 'work', and having 'other priorities' as main personal barriers to physical activity [277]. In line with these findings, Justine et al. (2013) reported 'too tired', 'already active enough', 'don't know how to do it', 'lack of motivation', and 'too lazy' as additional internal barriers and 'no one to exercise with', 'lack of facilities' as additional external barriers for middle-aged and elderly adults [145]. Lack of time may indicate a busy schedule, but can also reflect poor motivation or other priorities, linking back to other frequently mentioned barriers. After all, we all get to spend the same amount of time each day. 'I don't have time' could therefore also be interpreted as 'I don't want to spend my (limited) time on this'. People tend to prioritize things we perceive as imminent needs and, when those are handled, things we enjoy and make us happy [217,225]. Additionally, low self-efficacy and higher weight relate to higher perceived barriers [30,307]

With limited time, high costs, low motivation, and competing priorities among the main reasons to remain inactive, physical activity appears to be a luxury reserved for those who have the time and resources to engage and a chore for those who lack motivation. Focusing on physical activity accessibility, offering flexibility and tying in with busy schedules, increasing the sense of urgency (awareness) of its importance, as well as boosting exercise enjoyment and post-workout positive effects can thus help to address these barriers and encourage active behavior.

1.1.3 Taking on the Task

To alter the negative trend of physical inactivity, we first need to understand why the high level of awareness does not seem to trigger the desired change in behavior. We can also learn from prior work done to address this challenge, looking at their effects and reception.

Due to its scale and impact, the issue of physical inactivity has received a lot of attention from different research fields, including (but not limited to) public health, behavioral sciences and psychology, urban sciences, and design. Next to analyzing the problem and increasing awareness, this had already led to designs, technologies, policies, guidelines, and other initiatives aiming to help people to improve their inactive lifestyles or behaviors. These solutions can be divided into several categories, each tackling the challenge from a specific perspective. The WHO (2022) distinguishes digital solutions (e.g., to track activities), accessible sports/ ensuring sports for all, investing in physical activity, promoting active transport (walking and cycling), and finally strengthening partnerships between public and private sectors around the globe [340]. Kahn et al. (2002) distinguish between informational, behavioral and social, and environmental and policy approaches to increase physical activity [146]. The influential environmental factors can be further classified as the natural environment, built environment, social environment, and individual environment [89,342]

Developments towards this goal can be seen across disciplines. From a policy perspective guidelines are developed and distributed, awareness campaigns are organized, and healthy active or sports initiatives such as neighborhood sports coaches are subsidized and facilitated [224,317,326]. Behavioral and social scientists have analyzed the workings of human behavior and means to adjust it towards more active habits, while tech-companies and human-movement scientists have developed wearable devices that provide training schedules, guidance and feedback while recording activities [76,208].

Also within the design community, we see promising developments that can contribute to addressing physical inactivity. In the upcoming sections, we will discuss these developments in (1) urban design and planning and (2) industrial design and human-computer interaction.

1.2 Urban Design & Planning

1.2.1 Healthy Environments

A growing body of research shows that the design of urban environments can contribute significantly to healthier lifestyles (including physical activity levels) [36,148,274,275,291,327] as living environments strongly impact people's routines [36,148,167,275,291]. Additionally, a supportive environment is needed to achieve individual behavioral change [233]. This includes the physical environment as well as supportive social and organizational structures. Creating healthy living environments is thus increasingly prioritized by governing bodies, institutions and practitioners [167].

Looking at places where the (physical) environment plays such a positive role in general health, Buettner and Skemp (2016) studied the so-called Blue Zones; the places in the world where people live the longest. Of the nine commonalities found between these places, the first one is: *"Move naturally. The world's longest-lived people [...] live in environments that constantly nudge them into moving without thinking about it..."* [42]. As such, the way urban environments are shaped can contribute to both the physical inactivity and physical activity of inhabitants. Through their design, these environments have the potential to contribute about 60% of the recommended 150 minutes of physical activity per week [275].

1.2.2 Challenges and Barriers

Despite ample knowledge about the effect and design of 'healthy places', including places that encourage physical activity, other matters seem to have taken priority in the design of urban areas [108]. As a result, the way urban environments are shaped is often more likely to have negative health implications. [42,275]. For instance, areas designed to facilitate car use with a focus on 'convenience' encourage inactive behavior and therefore contribute to related health conditions such as obesity and diabetes. Additionally, this further reduces environmental quality as lack of public and green spaces together with noise and exhaust fumes further decrease opportunities for physical activity [108,337].

Next to their considerable potential to help support healthy and active behavior –like for most large-scale urban projects– designing these healthy environments comes with several challenges. For example, it takes quite some time to go from registering a need or opportunity for an improved space to the moment that the redesigned space is ready to use. Because of this long timespan, the actual finished space is always designed for the needs or wishes of stakeholders from the past and may therefore not quite fit the current use. Also, the actual effect of the design is hard to test before it is fully implemented and at that point quite unchangeable [1,240].

The focus in this field has been mainly on the collective, as a single, static space should serve many different users for a long period of time. This requires a thorough understanding of the average or group behavior in order to predict and serve future use, but leaves little space to consider individual desires and behaviors but. New and improving technologies are increasingly used to address these issues, both by improving the predicted future use through data collection and analysis and by enabling a more iterative design approach [106,227].

Considering the estimations of a high increase in urban living, the stakes are thus high to create healthy urban living environments. This is increasingly prioritized by governing bodies, institutions and practitioners [98,167].

1.2.3 Active Environment Design

With increasing knowledge about the impact of the living environment on health and quality of life, active environment design has become a popular endeavor in both Urban Design practice and research [136,148,291]. Much mentioned strategies to encourage physical activity through design of the urban public space include stimulating active transport, ensuring safety, more and better urban green, improving attractiveness –this includes removing pollutions–, mixed-use areas, and proximity and accessibility to facilities [26,90,229,291,337,342].

Already a main indicator for the attractiveness of the environment, the presence of green and water also influences active behavior in another way. Exercising (and residing) in green environments evokes a state of mindfulness that can increase the positive effects of experiencing nature [47] and, by extension, those of outdoor exercise. These positive feelings can increase motivation for repetition [136]. Next to the spatial context, social factors play a major role when it comes to behavior in the public space [30,120,166]. Physical activities, especially in the shape of recreation, games, and sports, can be an effective tool for social inclusion and integration [166]. Social connection is thus a common motivation for people to be active [286]. At the same time, social cohesion and liveliness can uplift the experience of the public space [111,327].

As mentioned earlier, increasing exercise enjoyment can help to boost physical activity. The exercise environment plays an important role in the extent of this enjoyment [313]. This effect is reflected in much-mentioned guidelines for healthy and active environment design that include attractiveness and the presence of green or blue as positive stimulants for increased exercise and enjoyment [47,82,342].

1.3 Design and Human-Computer Interaction

Human-computer interactions are playing an increasing role in addressing physical inactivity and sedentary behavior through industrial design. Pervasive technologies allow detection and monitoring of physiology and behavior, such as physical activity levels [192]. Combined with certain design strategies, these technologies can become persuasive and can be applied to encourage and support people to alter their behavior towards their desired lifestyle [67,68,102]. These designs derive their persuasive power from prior knowledge about behavior and the process of behavior change at the core of their concept development.

1.3.1 Changing Behavior

In the field of psychology, much work has been done to study and describe the causes and manifestations of human behavior, seeking means to steer behavior changes [2,125,209,252]. Behavior change-related theories describe how behavior is influenced by intentions, expected effort, usefulness, ability, observing others, setting goals, and whether behavior is consistent with personal values [234]. Based on these strategies, various frameworks and approaches have been developed that can be applied to alter behavior [2]. This knowledge can in turn be used to shape designs and use technology to encourage behavior change [24,53,184]. The work in this dissertation builds on this body of knowledge to support and encourage active behavior. In this section, we describe several of the relevant frameworks and strategies that have played a part in forming that base as well as the main ethical considerations.

Frameworks

Fogg’s Behavior Model states that behavior change requires the presence of three principal factors: *motivation*, *ability* and *trigger*. This means that people will only change their behavior if they are motivated and able to do so and encounter a trigger that prompts the change [103]. Fogg distinguishes three categories of motivators: Pleasure/Pain, Hope/Fear, and Social Acceptance/Rejection. He also offers an alternative description of the term ability, being 'simplicity'. This way, he emphasizes that ability can be increased by making the behavior easier to do. Main elements that influence this simplicity are the amount of Time, Money, Physical Effort, Brain Cycles (i.e., 'brain capacity' or amount of thinking), Social Deviance, and Non-Routine needed to perform the activity. The last of the principal factors, 'trigger', tells people to perform the behavior now. There are three kinds of triggers; triggers that also hold a motivational element ('spark'), triggers that also simplify the behavior ('facilitator'), and triggers that just serve as a reminder ('signal'). Finally, Fogg also notes that all these factors can vary between individuals as well as in different contexts [103].

Michie et al. (2011) created the Behavior Change Wheel, a framework that brought together 19 of pre-existing works design and effect of behavior change interventions and that can be used to characterize such interventions [210]. At the center of this wheel are three essential conditions that they call the COM-B system: motivation, capability and opportunity [210]. We see a strong overlap with Fogg's principal factors here. In the second layer of the wheel, nine intervention functions –or strategies– are positioned that can be used to address shortcomings in the essential conditions. The third layer displays seven policy tools that could enable such interventions and/or increase their impact.

The Transtheoretical Model of behavior change (TTM) [252,253] regards changing behavior as a process that consists of six stages of change. It starts with *precontemplation*, where a person has no intention (yet) to change their behavior in the near future. This becomes *contemplation* when they are aware that something is not right and a change would be desirable to address that but they have not yet committed to taking action. The next stage is *preparation*, when the decision is made to change. There is a serious intention to take action and sometimes small changes are already made. This is soon followed by *action*, as behavior, experiences, or environments are altered to overcome the problem. When a certain mark or criterion is reached, action turns to *maintenance*, where the focus is on preventing relapse and stabilizing the achieved gains. During the final stage, *termination*, there is no more temptation to return to the old habit. Since relapse is a common occurrence, this process is not so much linear but rather spiral-shaped, as relapse causes a regression to (pre) contemplation followed by renewed resolve and action. The focus of the research related to this model is on the first five stages, as termination may be the ideal end of the cycle but it unfortunately is not a practical reality for the majority of people [253].

Strategies

Based on these frameworks, several strategies can be developed to stimulate behavior change through intervention design.

From the various behavior change models we learn that motivation is a key factor in achieving behavior change. As motivation and motives again vary per person, an individually tailored approach can also be used to strengthen motivational messages [325]. There are several strategies that can be used to stimulate desired behavior by increasing motivation. Setting goals, offering rewards and social stimuli through sharing, support and competition can increase external motivation [174,219,273]. Raising awareness, self-monitoring, and reflection are more internal motivators [130,192,219]. Enjoyment of the desired behavior is a strong indicator of performing it [277]. Triggering curiosity and providing autonomy have proven to be effective methods to influence motivation in several cases [28,103,284]. Stimulating exploration and discovery have been shown to boost the curiosity process [314] and evoke positive emotions [353]. Alongside these strategies, there is the 'feel-good' factor; the positive psychological impact of the behavior. This is also a main factor for physical activity and exercise [30] and as such contributes to a positive experience. This is important to note as a main part of what draws people toward physical activity and exercising, or many other activities for that matter, are the elements that make it enjoyable [136]. Similarly, higher enjoyment and satisfaction are likely to foster a greater intent to repeat the activity [213,313]. It can thus be an effective strategy for active routine encouragement to focus on a pleasant, enjoyable and satisfactory experience instead of health benefits and increased performance [213].

In the design and HCI community, interactive technology is, among others, used to create personalized designs and solutions [297]. When aiming for behavior change, persuasion to perform that change is an important design challenge. This persuasion is most effective when the right message is delivered at the right time and in the right way [50,85,147]. The type, content, and timing of this 'right' message varies between the individual people that make up the target users. This is why personalized approaches are likely to be more effective than general or standardized ones when trying to influence a large, heterogeneous group [28,30]. Information about those individuals, such as personal user data, can help to tailor persuasive technologies and thus increase their effectiveness in establishing behavior change [28,147,235]. This is also true for interventions aimed at increasing physical activity [30]. Building on these principles, advances in smart, connected, and interactive technologies have enabled a shift from a one-size-fits-all approach to solutions that can adapt to their user and/or context [28,50].

In the context of encouraging behavior change, nudging has become a much-used strategy. Nudges are subtle prompts that gently guide people in directions that will make their lives better, without taking from their freedom to choose [310]. This concept of nudging has been well adopted in HCI and is used to design systems that can adjust behavior by presenting information and choices in certain ways [50]. This way, nudges can be used to alter lifestyles [104]. Hansen and Jespersen (2013) distinguish four types of nudges, based on them addressing the conscious or subconscious mind and whether they are transparent or not. Both non-transparent types are called *manipulation*; of behavior when addressing the subconscious mind, and of choice when addressing conscious decisions. Transparent nudges are defined as *influencing* behavior when addressing the subconscious mind and *prompting* a reflective choice when addressing conscious decisions [129]. The nature of nudges can be positive, such as when appealing to or increasing empathy, neutral, by offering feedback or suggestions, or negative, by using fear or deception [50].

An issue with many behavior change intervention studies and solutions is the novelty effect [158]. New and unfamiliar things typically draw attention and inspire curiosity, triggering people to 'try it out' or perform a closer examination. This initial excitement, however, wears off after some time [271]. When people are used to the change, it becomes part of the everyday environment and thus loses this part of their initial attraction. In order to learn about long-time effect of changes, they either need to be observed over a longer time [221] or account for this drop of impact in another way [272]. For more adaptable solutions, the novelty effect can be renewed over time by changing interactions, adding features and/or altering goals [158].

Ethical considerations

The concept of purposefully changing behavior through interventions also brings ethical concerns [322]. These include questions about what type of behavior is 'desired' and who gets to decide this, since what is desirable for one person may not be so for another, and what is desirable for an individual may not match what is desirable for the group [144,149]. Additionally, while people should be able to make informed decisions about their behavior, awareness of the persuasive strategies of an intervention could also undermine its effect [149]. To address these concerns and create ethical interventions, the desirability of the target behavior must be grounded in trustworthy evidence. Designers must consider possible (side)effects for all stakeholders [155]. For this, users and other stakeholders should be included in the design process to properly acknowledge their views and build ethical consensus [144,149].

The established behavior change research, outlined in this section, clearly articulates how multifaceted and challenging it is to change people's behavior. The presented frameworks and strategies provide valuable handles when designing for more physical activity.

1.3.2 Designing for Behavior Change and Increased Physical Activity

In their efforts to address the physical inactivity challenge, the design community uses these strategies and frameworks as foundation for their work when designing for behavior change, including designs that aim to stimulate physical activity [24,53,67,184]. Such interventions require a combination of disciplines to be effective. For the HCI and design communities, it requires integration of design, behavior science, and HCI technology.

A way to do this was introduced by Zimmerman et al. (2007). They proposed a *Research through Design* approach as a method for interaction design research in HCI [358]. Since then, design and HCI have grown closer, with their research communities overlapping [165]. HCI technologies offers new interactions, adaptability, and personalization opportunities for designs. At the same time design has gained a more central position in HCI developments, bringing empathy for the users and integrating art, design, science and engineering to create aesthetically functional interfaces [358]. Research through Design is later further defined as a way to conduct design research. Design differs from other scientific research in that it pursues the non-existing and creating the ultimate particular [298]. Research through Design thus builds on documenting the design process so that others can reproduce it, without expecting that this will result in a similar design solution [357].

As changing behavior is a very complex process, design solutions aiming to accomplish it often focus on a specific part of the behavior or decision-making process. They then use strategies and intervention points to optimize that part of the behavior change process, hoping it will impact the entire process enough to establish the desired change. The same goes for the more specific case of behavior change that is increasing physical activity. Interventions coming from the HCI and design field also typically target individuals [104]. This may be because behavior is considered the result of an individual decision-making process and thus requires an individual approach. It could also be because of the (added) complexity of addressing it at the population level [104].

Often, the resulting designs contain a combination of strategies. A popular medium to support physical activity are mobile applications, sometimes combined with wearable sensing and monitoring devices. These often focus on self-monitoring and self-regulation and offer a combination of goal-setting, rewards, reminders or suggestions, and sharing [199,208,219]. They provide insight into actual behavior by using tracking technology and presenting the collected data to the user. This helps in increasing awareness while supporting goal-setting, progress tracking, offering praise and rewards in a personalized experience [239]. Data sharing is encouraged by a variety of dialogue and social support features that facilitate social motivation. Combined with training programs, such applications can also increase self-efficacy of users as they can take control of their training schedule without consulting a coach or specialist. However, techniques that specifically address self-efficacy are less commonly used [199].

A variety of more tangible designs trigger active behavior change in different ways. As physical objects, these tangible interfaces become a part of the physical environment. As such, they are more visible and persistent and more likely to be integrated in daily routines [359]. Other designs use interactive multimedia displays, providing an immersive experience such as enhancing traditional sport or gameplay through an interactive digital layer or a 'bouncing' floor that provides body-interaction feedback [83,218,259] using sound, light and/or other modalities to shape their interactions. For such interactive public displays, users go through different phases of interaction (Passing by, Viewing and Reacting, Subtle Interaction, Direct Interaction, Multiple Interactions, and Follow-up Actions) or participation (Transit, Awareness, Interest, Intention to Participate, Participation/Play, and Intention to Stop) as described in the Audience Funnel by Müller et al. (2010) [218]; and the Participant Journey Map by Mast et al. (2021) [196]. In both models, certain thresholds separate the different phases and must be overcome to move to the next phase. By lowering these thresholds designers can increase participation, amplifying the behavior change impact of the installation.

As can be seen from these engagement stages, investigating in-context use and actual effect of design interventions is an important part of the process [358]. With all its interlacing aspects and impacts, it is hard to study a phenomenon like design in its entirety in a decontextualized 'laboratory' setting, though the controllability of such an environment can be used to test certain specific design elements. The opposite approach brings the design into the 'field', its expected natural setting. Though this environment is far less controllable and therefore allows for many unpredictable external influences, it enables researchers to study the design in its real-life context [165]. This becomes more complex when the designed experience is more immersive, and that context is the public space. Building on research through design principles, Megens et al. (2013) developed the *Experiential Design Landscapes* method [244]. This method is aimed at achieving structural behavior change through designs that are part of normal society, embedded into the daily living environment. It brings the design research team to people's everyday lives, where interactive, intelligent interventions called Experiential Probes are created, tested, and tailored [205,244].

While the focus of most behavioral research is on understanding behavior, at most changing one variable at the time to run controlled experiments, the Design community presents valuable means to embrace the complexity and experiment with larger scale changes [316]. The methods and frameworks presented in this section form the foundation of our approach.

1.3.3 Designing with Data

With the ever-increasing integration of technology in our daily lives, designers have access to more (digital) data than ever. Proven useful for analysis and decision making in many disciplines, this trend has additionally uncovered new roads for exploration and the use of data in the design process [170,350]. While there is often an overabundance of data related to user behavior and experience, the development of methods and tools that allow creative engagement with sensor-generated field data in the context of design processes has only begun in the past few years.

Next to instinct and experiments, in recent years, designers have started to incorporate data to shape both decisions and solutions [169,170,285]. There are many ways this can be done, depending on the challenge and stage of the process. King et al. (2017) describe three approaches toward data in the design process: *data-driven* design, *data-informed* design, and *data-aware* design [155]. When the research question or design challenge is unambiguous and precise, (empirical) data can provide a clear and definite answer and thus *drive* the design decisions directly. When uncertain variables ask for more nuanced design decisions, data can be regarded as one of many inputs into the decision-making process. This often leads not directly to a decision, but *informs* another iteration, investigation, or creative leap. Finally, for all data design it is important to be *aware* of the landscape of available data, considering how and what data types should be collected and combined to address the challenge at hand [155]. In such a process, access to data is not enough. When used in design enquiries, data needs to be explored creatively in search of novel insights and explorations, throughout the process, and used for its strengths [170]. Kun et al. (2019) constructed a *Exploratory Data Inquiry* framework to help designers to make methodical considerations of data work around a creative process, covering three steps: gaining understanding and framing the right problem, open-ended data exploration following an opportunistic mindset to evolve the problem-design space, and reaching conclusions and gathering answers to the leading questions [169].

Such approaches, however, still only address data in the design process, while with increasingly 'smart', interactive, and interconnected products, data is also becoming an inherent part of the design solutions themselves. The term 'smart' product indicates the presence of advanced feedback algorithms or a connection to other devices, typically aimed at optimizing processes and making life easier [282]. However, the actual intelligence of such products is easily challenged and brings a new set of ethical and practical concerns. Streitz (2019) defines three basic problem sets with current implementation of 'smart' solutions: (1) *Inability* to gain real understanding of the situation leading to *error-prone behavior*; (2) *rigid behavior*, as the system cannot handle even small deviations from the standard routine; and *(3) missing transparency, traceability and accountability*, as these 'smart' solutions are becoming less transparent and comprehensible, the underlying argumentation for their mechanisms becomes hard to trace, leading to a lack of accountability and liability [305].

In becoming 'smart', products and services have developed a need to collect and process a variety of data from their users. Depending on the nature of these data, this may also lead to privacy risks, especially when a lack of transparency makes it difficult to grasp who is collecting what data and for which purpose [293,297]. For designers of these products, it is therefore important to be open and transparent about the purpose and type of data collection. However, for exploratory work where data collection is used to comprehend design context it is often difficult to provide such details beforehand [160]. As aforementioned, giving too much information may also influence the intervention effect. Designers therefore have to balance these arguments carefully for each project, as well as limiting and de-identifying the personal data they collect [135,293,297].

With the term 'smart' being used for all kinds of products and services, critics also stress their technology-driven nature and the need to include a more humane, user or society centered perspective [282,305]. Some propose new terms that address these shortcomings and define a clearer scope, such as moving from smart to 'wise' design that requires an adaptive approach [282], or from smart products to intelligent solutions that gains detailed understanding of its user and context and can adapt its interactions as this develops over time [160]. All these solutions have data at the core of their interaction or service. For such products, data has become more than an information stream. It has become a material to design with and should be regarded as such throughout the design process [160].

In this section we articulated two opportunities for a more prominent use of data in design. On the one hand, it can enhance the design process, either by generating evidence for design decisions or by inspiring new design iterations. On the other hand, solutions become smarter and data plays an instrumental role in that. This trend is especially relevant for our work, as it can help us to understand the impact of our explorations and brings new opportunities for more personalized solutions.

1.4 Moving Toward Each Other

Looking at these developments, we see the fields of urban design and planning and design and HCI moving closer towards each other. To address the challenges of urbanization, urban designers are increasingly using ICT and data-driven solutions in their city plans, creating so called 'smart cities'. At the same time, the increase of embedded and interconnected solutions is requiring Design and HCI solutions to consider and design environments rather than individual objects. In this section, we will discuss these movements that bring these fields closer together from both sides.

1.4.1 Smart Cities

To optimize infrastructure and services, increase efficiency and sustainability, and improve quality of life for their citizens, cities are increasingly equipped with integrated smart solutions. While these *smart cities* all use ICT, data, and other smart solutions to reach their objectives, many definitions have been provided to describe this concept [13,16,31,151,216,289,315]. Disparate definitions follow various perspectives or highlight different motives to implement smart city technology. In general, the focus of these motives has shifted over time, moving from a technocentric vision of optimizing processes and minimizing cost to becoming more sustainable, including community needs, and an increased focus on the people and their quality of life [13,31]. Still, Mohanty et al. (2016) have identified four main attributes that make up the majority of smart city proposals; *sustainability*, *quality of life*, *urbanization*, and *smartness* [214].

In a smart city, digital technologies and data science are used to connect the physical, IT, social, and business infrastructures to form an integrated framework that enables the collection, combining, analyzing, and optimizing of operational data. This can inform or even drive decision making, improve urban planning [279], and increase the city's ‘intelligence’ [131]. This means it contributes to enhancing performance efficiency and quality of services, as well as to exploiting operational data to improve efficiency, sustainability and quality of life [131,151,201,289].

Examples of such optimized systems include intelligent transportation systems that use real-time traffic data to optimize traffic flow, smart streetlights that adjust their brightness according to time of day and the presence of pedestrians and vehicles, or smart waste management systems that use sensors in bins to optimize trash collection routes. Through remote monitoring and reducing response times, optimized systems can also contribute to improved healthcare and public safety. In more general terms, smart city solutions allow for more flexibility and adaptability in an interconnected system. At the same time, they facilitate increased collaboration, engagement, and participation of stakeholders by offering digital communication and data-collection media. This is a significant element, as a citizen-centered approach where the imagination and collective intelligence of a city's inhabitants are used to shape future cities is increasingly important in urban planning [16,216,247].

Integrating digital, human, and physical systems to address these many goals, smart city development has become a multi-disciplinary endeavor [45] that requires incorporating expertise in ICT, HCI, IoT, and data science next to urban planning. The addition of digital technology enables new and enhanced ways for tailored design and personalization, which are typically more impactful in design for motivation and sustained behavioral change than universal designs [235] and align well with a focus on citizen wellbeing and quality of life. Urban environments already have the potential to strongly contribute to physical activity through their design [275]. Adding the possibilities of evolving and increasingly integrated digital technology may well enhance this effect, while continuously adding new opportunities [6,297].

1.4.2 Human-Environment Interaction

In the field of Design and HCI, the availability of more data and ever-improving digital technologies have resulted in an increase in ‘smart’ designs and solutions, introducing computers –and HCI– to all parts of daily life. As a result, computers are becoming more powerful and able to react attentively and adaptively. They also get more ubiquitous while spaces and objects are becoming ‘smarter’ through their –often interconnected– presence. Additionally, these computers are disappearing from their user’s perception as they are increasingly embedded in the environment. This makes them less noticeable and causes an experience of interacting with the environment itself rather than with a computer [112,138,297,306]. These developments have resulted in a shift from Human-*Computer* Interaction to Human-*Environment* Interaction [297,306].

The increasing pervasiveness of digital devices and their interconnectedness brings a shift from user experience to community experience. This altered perspective, also referred to as *macro-HCI*, offers additional opportunities to refine persuasion theories. Combined with big-data analytics it can also produce meaningful insights in user behavior and experience, supporting bottom-up improvements of such systems [288].

The way these new technologies are inconspicuously present in everyday living environments support new ways of interactions [297], which makes them quite suitable for technology-mediated nudging [50] and other persuasive technologies [28] that build on behavior change techniques.

These developments have led to a growing share of HCI researchers working on understanding and shaping experiences with and within the built environment. This interdisciplinary area situated at the intersection between HCI, architecture, and urban design is also referred to as *Human-Building Interaction* [6,7,226]. This term, however, is also used in the Built-Environment community to refer to buildings smartly adapting to their user's needs in terms of heating, ventilation, air conditioning (HVAC), and energy efficiency [72,143,171]. The use of this same term in both fields for related but different concepts illustrates their movement towards each other as well as their dissimilarities. Developing the interdisciplinary field at the intersection signifies a transition from *artifact* to *architecture* on the one hand and from *spatial design* to *interaction design* on the other. This brings a shift in scale and focus that requires reconciling differences in methods, frameworks, and terminology from both fields [6].

1.4.3 Research at the Intersection

Investigating the potential and opportunities at the intersection of disciplines, this doctoral research is affiliated with two faculties of the Eindhoven University of Technology, those of Industrial Design and the Built Environment. In both departments there has been a strong interest in using new methods and technology to stimulate physical activity through design, with a focus on active transport in the Built Environment [12,181,183,250] and on the use of smart, embedded, and interactive technology in Industrial Design [77,160,206,244,258]. This research builds on the work and research traditions of both fields.

1.5 The Work Presented in this Thesis

Design offers opportunities to encourage, persuade, or push people toward more active behavior in various disciplines. The research described in this thesis builds on knowledge from active environment design, human-computer interaction, design for behavior change, and data design, which is tersely described above. Bringing together aspects that contribute to and encourage physical activity from these fields, it aims to increase the positive effect of active urban environments by designing and embedding interactive technologies in those spaces. Therefore, the aim of this thesis is to

> *investigate how we can design for active urban environments by integrating data and interactive technology in their design process and the resulting design solutions.*

To do this, we divide our research into four parts: *Active Environments*, *Toward interActive Environments*, *Perspectives on Data*, and *Pathfinder*. The first three parts each address one of the following questions:

1. *What is already known about active environments and the way they are realized?*
2. *How can integration of data and (interactive) technology enhance the positive effects of active environments?*
3. *How can we use –and regard– data to address the challenges and opportunities that arise from working at the intersection of disciplines when creating interActive Environments?*

The fourth part brings together insights from all of them in a final case study.

1.5.1 Thesis Overview

This first chapter has provided a general introduction of the societal challenge we set out to address and the related work we will build on. In the following parts and chapters, we will address our research challenge.

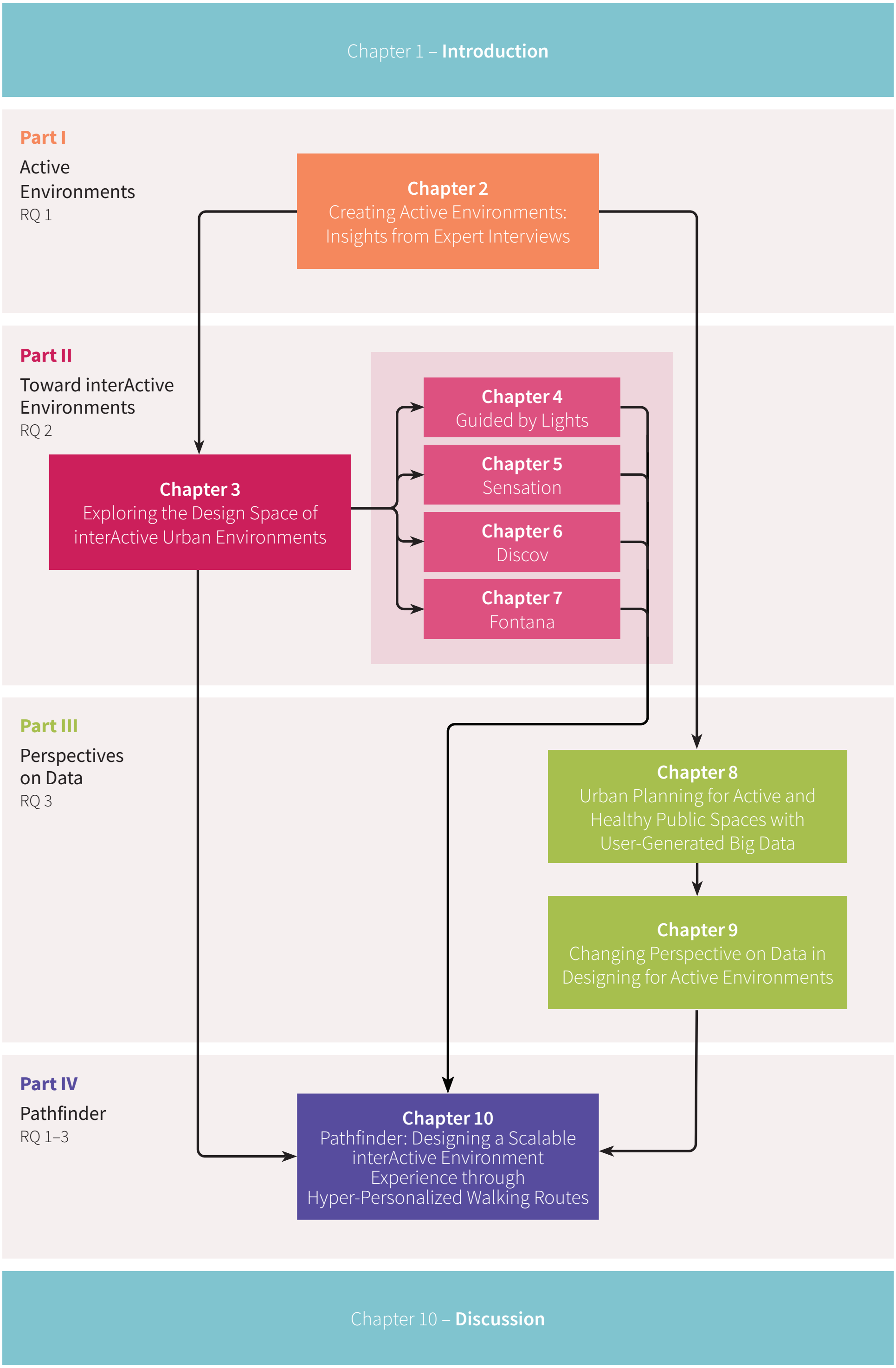
In the first part, we investigate *Active Environments*. Here, we outline existing knowledge from practice and research in the field of active environment design and realization. In chapter 2, we discuss definitions of active environments and their added value to encourage active behavior and provide an overview of the spectrum of design strategies, elements and boundaries used to create them. We also describe typical steps in the design and realization process, including types of stakeholders, main gaps, and points of friction in this practice.

In the second part, we move *Toward interActive Environments*. We explore how integration of data and (interactive) technology can enhance the positive effects of active environments. Through sketches, a benchmark of existing concepts and an analysis of designed artefacts, we map the different intervention levels, interaction modalities, behavior change strategies and technological opportunities to design such interActive environments in chapter 3.

Several of the derived concepts we investigate further through a series of design explorations, captured as case studies. Through these designs, we explore the use and effectiveness of solutions that (1) positively impact motivation and/or performance through personalization, goal setting, and feedback mechanisms (chapter 4); (2) encourage more physical activity by improving the experience (chapter 5); (3) reinforce existing active behavior (chapter 6); and (4) stimulate physical activity and social connectedness using the multidimensional attractiveness of water (chapter 7).

In the third part, we discuss *Perspectives on Data* related to this research. Here, we look more closely at how data is used and regarded in the fields of Urbanism and HCI and how these perspectives can be leveraged when designing for interActive environments that exists at the intersection of these disciplines. We start in chapter 8 by studying a large user-generated dataset from a run-tracking smartphone application. Using an explorative and iterative research approach, we gain understanding in what environmental factors contribute to optimized running climates.

Next, we investigate how such user-generated big data can support designers in shaping more


Chapter 1 – Introduction
Part I
Active Environments
RQ 1
Chapter 2
Creating Active Environments: Insights from Expert Interviews
Part II
Toward interActive Environments
RQ 2
Chapter 3
Exploring the Design Space of interActive Urban Environments
Chapter 4
Guided by Lights
Chapter 5
Sensation
Chapter 6
Discov
Chapter 7
Fontana
Part III
Perspectives on Data
RQ 3
Chapter 8
Urban Planning for Active and Healthy Public Spaces with User-Generated Big Data
Chapter 9
Changing Perspective on Data in Designing for Active Environments
Part IV
Pathfinder
RQ 1–3
Chapter 10
Pathfinder: Designing a Scalable interActive Environment Experience through Hyper-Personalized Walking Routes
Chapter 10 – Discussion

activity-friendly and adaptive environments by introducing two data lenses in chapter 9: a *collective* and an *individual* lens. Through exploratory data visualizations, using the same running dataset combined with public data sources, and a workshop, we investigate how these lenses can yield meaningful insights for the urban design and HCI communities.

In the fourth and last part, we conclude in chapter 10 with ***Pathfinder***, an extended case study that explores an alternative perspective on interActive environments, where we investigate how to address scalability challenges and further explore the use of big data to drive such solutions through AI.

Through these investigations we explore and reflect on the concept of interActive environments and how these can help in stimulating and encouraging more active lifestyles. In the Discussion in chapter 11, we reflect on our findings, how these are situated in the related work, and implications for future work.

1.5.2 Contributions and approach

Our goal, to *investigate how we can design for active urban environments by integrating data and interactive technology in their design process and the resulting design solutions,* asks for a broad research approach that recognizes and appreciates different elements at play in this context. In addressing this challenge, we will make several contributions to the theory and practice of designing for more active lifestyles [347]. We offer empirical contributions by presenting a collection of studies that bring new findings based on observation and data-gathering (chapters 2-10).

Starting from a broad investigation of the context, we continue our exploration on two parallel paths that further examine the main opportunities found. We present design artifacts that illustrate new applications and opportunities to address less explored angles at the intersection of the fields of design, HCI and urbanism (chapters 4-7 and 10). These prototypes are deployed for in-the-field user testing to iteratively improve their concepts and further investigate their potential. The second path studies the opportunities presented by the new and increasing flow of data in this context, offering insights in and new ways to regard and capitalize on this information base (chapters 8-10). This work also brings theoretical and methodological contributions, as it transcends traditional discipline boundaries and bridges between research fields, offering insights and recommendations for a combined approach (chapters 3, 8-10). Insights from both tracks are brought together in a final study and prototype to unify these findings and gain a comprehensive understanding of interActive Environments (chapter 10).

part I

Active Environments

In the introduction, we have seen that urban planning and design offer opportunities to nudge people towards more active behavior. This is a popular topic among urbanists and health professionals, with several guidelines and best practices already developed. However, a gap exists between theory and practice and the complex realization process of such active environments is rarely documented. In this part, we investigate what is already known about active environments and the way they are realized. We describe the process of designing, implementing, and evaluating active urban environments, including main design elements, strategies, and challenges. For this research, described in chapter 2, we conducted semi-structured interviews with 11 European practitioner experts in the field of active environment design and development. We analyzed the 51 examples of active environments they provided. We discuss definitions of active environments and their added value to encourage active behavior and provide an overview of the spectrum of design strategies, elements and boundaries used to create them. We also describe typical steps in the design and realization process, including types of stakeholders, main gaps, and points of friction in this practice.

Creating Active Urban Environments

Insights from Expert Interviews

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2.1 Introduction

Frequent physical activity is a well-known and key part of maintaining a healthy lifestyle [42,238,334]. However, it still proves difficult for many people to embed this in their lives [33,159]. Finding effective ways to encourage people to be more active and helping them to maintain a healthy lifestyle by promoting physical activity is thus a critical endeavor to increase public health [92,159,334,335].

For people to change their behavior, contextual characteristics play an important role next to individual ones. This encompasses both the social and physical context. Regarding the latter, a growing body of research shows that the design of urban environments can contribute significantly to increased physical activity levels [36,148,275,291], as living environments strongly impact people's routines and therefore public health. Creating healthy living environments is thus increasingly prioritized by governing bodies, institutions and practitioners [167].

2.1.1 Healthy Placemaking

'Health' is a multidimensional concept [180]. The WHO describes it as a state of complete physical, mental and social well-being [331], which encompasses a vast collection of determinants of both internal and external origin. A healthy environment, in the broad sense, should provide optimal conditions to improve and maintain external factors. Next to the design of the physical environment, this entails matters such as good air quality, clean water, sanitation, and a wholesome socio-economic and political climate [180].

There are multiple advantages to intervening at the environment level to increase public health. Though people's living environments are multi-faceted and complex, the physical environment remains a constant, integral part. The way places are designed can therefore strongly influence behavior [146,167,327]. Making chances in the public domain ensures the accessibility and context aware decision-making needed for a population-based approach [104]. Additionally, well-designed public spaces can stimulate social interaction and provide a sense of security [186]. To do this effectively, knowledge about people who use the public space –how they use it, perceive it, and their desires for improvements– is essential. This asks for an approach that values and uses these insights to create public places of everyday life, also known as *placemaking* [312]. When adopted well, such an approach can be transformative in affecting how people live, leading to a better, more livable public realm [191]. This makes *healthy* placemaking, where the urban space is reshaped to improve people's quality of life [29,186], an important practice.

The multifaceted nature of 'health' requires a holistic approach towards creating such places. In this research, however, we narrow our scope to focus on *active living,* defined by Edwards and Tsouros (2008) as a way of life that integrates physical activity into daily routines [90]. Although many forms of physical activity can improve overall health, integrating physical activity of at least a moderate intensity into daily routines is found to be most effective [90]. From an urbanism perspective, this means that while dedicated sport- and recreation facilities remain important, the focus should be on shaping *daily urban systems* (DUS) in such a way that they support and encourage more active routines.

The practice of active environment design is gaining traction in the urbanism field, keeping pace with growing awareness of their influence and the urgency of the public health issue. As such, it is becoming an integral part of healthy placemaking practices and providing a growing body of research [90,104,166,203,278]. Since physical inactivity is a public health issue with a large part of the population as the target group, population-based approaches are often preferable over ones focusing on an individual-level [104,146,257]. However, in their scoping review, Forberger et al. (2019) note that most interventions aiming to increase physical activity only target specific population groups and/or focus on certain settings, specific technology, or particular disease prevention. Additionally, all interventions they reviewed targeted the micro-level, with mostly point-of-choice prompts targeting the individual [104].

2.1.2 Healthy Active Placemaking

The concept of active environments, also referred to as 'activity-friendly environments' [164,308], 'activity-friendly neighborhoods' [148,275], 'activity-promoting environments' [121,292] or 'active living infrastructure' [121], defines physical places, typically in an urban context, that through their function and design increase physical activity levels of their users. The goal is to increase public health on a population level, and to improve quality of life, making it closely related to –and a main part of– healthy city and healthy urban planning initiatives [22,90,186]. The urban context brings with it an emphasis on active living, with *active transport* (walking and cycling) as a core element [42,116,166,291]. This includes not only proper sidewalks, bike lanes and crosswalks but also street connectivity and access to public transport and facilities, leading to a preference for *mixed-use areas* and higher population density [90,148,166,291]. In addition to increased *accessibility*, the presence of parks, green and playgrounds is often mentioned as an important and influential factor regarding physical activity [3,90,163,291]. Next to these physical properties, it is also important how the environment is *experienced* [82]. This is why a higher sense of *aesthetics* (experienced beauty) [3,166,177,278] and perceived *safety* are important factors [148,177,278].

The number of healthy-active placemaking initiatives, together with numerous guidelines provided in the literature on how best to do this, shows that this is a timely topic in practice and research. However, both appear focused on providing directions or listing components needed to establish these places, highlighting the key design elements mentioned above [90,132,166,320]. Details about the process and its impact remain largely overlooked.

2.1.3 Challenges to Address

Despite the abundance of such guidelines for designing active environments, Frumkin (2003) points out that critical questions such as '*Says who?*', '*Does this actually make people happier or healthier?*' or '*How would success be measured?*' often remain unanswered due to a lack of solid validation [108]. This is remarkable, because implementation should be followed by evaluating the process, sharing results and reviewing the plan [14,90]. Similarly, O'Neill and Simard (2006) outlined the constantly reappearing dilemmas causing this gap in five questions about the *why*, *what*, *who* and *how* of these evaluations. They stressed the need for such evaluations, rejecting uniform approaches and advocating tailored evaluation for each project [232]. Still, in the literature, project evaluation often happens long after completion by comparing characteristics between several 'successful' locations as done by Kostrzewska (2017) [166] and Sallis et al. (2016) [275]. In practice, evaluation appears rare.

Scheepers et al. (2014) did find and reviewed eight evaluation studies of environment adjustments to promote active transport. They also noted a large gap between the number of implemented interventions and those tested for effectiveness [281]. The absence of structural impact evaluation thus remains [104,203,232,278], leaving opportunities to learn from past success and failures unused.

An opportunity can be seen here to use 'smart city' technologies to collect additional before and after data. This is a growing body of increasingly embedded ICT technologies that constantly gather city data to advance performance [13,131], learn and address the challenges following urbanization and population increase [109,289], and increase and maintain quality of life [201,289]. 'Smart Cities' are characterized by being inclusive as well as their ability to adapt to their inhabitants' behavior [45,247]. For this, people have become an important resource [20,109,247,268]. Through visiting 'smart' areas and crowd dynamics, sharing self-reported data or joining participatory design practices, citizens themselves provide valuable input for governments and urban architects [18,111,247]. These data unveil patterns that can inform decisions regarding new policies or spatial designs [227,309]. The easy access to more data would suggest easier, better, and more evaluations. Unfortunately, this is not (yet) the case. Caird and Hallett (2019) even found 'strikingly little research' on evaluation of smart city interventions themselves [45].

Adding a digital context brings opportunities to capitalize on the potential of urban design to encourage physical activity. Simultaneously, it expands complexity in this challenge as it increasingly creates new venues for interventions, such as augmented reality or IoT solutions. Regarding the environment, this progress entails a shift from human-computer interaction to human-environment interaction or human-building interaction [6,306]. Here, environments become truly smart as their interactions become more human-centric, having not just sensors but more interactive technologies embedded in them [266]. This development asks for a more holistic and multidisciplinary design approach [297], that next to urban planning, design and public health, also includes experts on behavior change strategies and digital technologies.

Designing for public spaces encompasses a mixture of functions for a large, versatile and constantly changing user base, making it a challenging endeavor [196]. Healthy-active placemaking processes are therefore highly complex [186,281]. With many stakeholders and uncontrollable variables to consider, it requires comprehensive and interdisciplinary approaches [69,275,278] that are not always available [167]. The context-dependent nature also makes it hard to define generic measurable evaluation parameters [232]. Gaining more understanding of the workings of this process as a whole –the timeline, parties involved, steps taken, and barriers encountered– is therefore an important first step to determining and implementing evaluation methods and improving the creation process and post-occupancy effects of healthy active places.

In this chapter, we combine this knowledge from theory with that of practice [116,249]. By analyzing active environment examples and 11 expert interviews, we explore practitioners' definitions of active environments and their project experiences. We present an overview of main design strategies and elements used to shape active environments and provide insights into the process of creating them. We conclude with a description of typical steps in the design and realization process as well as main gaps and points of friction in this practice.

2.2 Method

2.2.1 Participants

We interviewed 11 experts (four females, seven males), between 30 and 60 years old. Participants were recruited from the authors' professional networks and additional snowball sampling, based on their experience in working on active environment projects. They were involved in projects located in north-west Europe and Portugal, with a majority in the Netherlands. This aligns with their main places of residence. Participants represented different roles in the design and realization process.

Our sample includes experienced practitioners and researchers from the fields of industrial design, data design, urban design and planning, policy making and physical activity innovations. Some participants had multiple areas of expertise. For an overview of participants, see Table 2.1. All participants had experience with the hands-on, practical side of creating active environments, which was the focus of these interviews. Several participants had additionally been involved in academic research resulting in (co-)authored publications describing design principles and guidelines for creating active environments.

ID	Gender	Age	Main Discipline	Context
P1	M	59	Urban Design and Planning	Industry & Academic
P2	F	32	Industrial Design	Academic
P3	F	38	Physical Activity Innovations & Society	Industry
P4	M	37	Industrial & Data Design	Industry
P5	F	32	Urban Strategy and Development	Local Government
P6	M	38	Industrial & Data Design	Industry
P7	F	33	Physical Activity Innovations & Society	Industry & Academic
P8	M	45	Physical Activity Innovations & Society	Industry
P9	M	51	Urban Design and Planning	Industry
P10	M	52	Public Health and the Environment	National Government
P11	M	46	Urban Design and Planning	Industry

Table 2.1: Participant demographics.

2.2.2 Procedure

We conducted semi-structured interviews that were held online via videoconference because of COVID-19 measures at the time of data collection. Based on our literature study and defined research scope, an interview guide was prepared in a session between the authors. The guide, provided in Appendix A, entailed four main themes: (1) *Active Environments:* Participants were asked to provide examples and their definition of what entails an 'active environment'. These were discussed, together with their important elements and potential perceived challenges, gaps, and opportunities; (2) *Collecting and Making Sense of Data:* Here, we discussed the types of data collected during such projects, how they are interpreted and used, and if this use includes monitoring or evaluation. We also discussed unavailable data that could have been helpful and views on using data in the design process; (3) *Illustrative Example:* Participants anecdotally described one active environment process they were involved in. The example included a timeline, stakeholders, decision-making, challenges and problem-solving. This helped to fill in gaps and offer more details about their definition of 'active environments', the process of making and monitoring them, and data collection and handling; (4) *Towards interActive environments:* Here, participants explain how they regard developments towards more interactive or even 'smart' environments in the context of active environments.

As preparation for the interview, participants were asked to come up with three examples of what they considered active environments, without additional indication of what types of environments we were looking for. This did not need to be projects they had been involved in themselves. We discussed these examples during the interview to gain insight into their perspectives on and definitions of active environments. The interviews were recorded and lasted between 50 and 105 minutes (average 75 min).

2.2.3 Data Analysis

All interviews were transcribed verbatim, then coded and analyzed with MaxQDA Plus 2020 using a thematic analysis approach. We conducted two coding rounds, both with a main and secondary coder. We first used open coding to code participant statements following the main interview themes. These led to a set of codes that were analyzed by the coders and grouped into themes, which were used for a second round of more deductive coding to further refine our results. The created codes were then collaboratively analyzed and discussed to extract definitions, key elements, opportunities, main challenges, and insights into the process of designing active environments. Quotes in this chapter were translated to English.

2.3 Results

In this section, we present our results following the findings and structure of our open coding strategy. First, we discuss definitions of active environments, their added value when aiming to increase physical activity in a population and main design strategies and elements to create them. We then focus on the process of realizing such environments, describing main challenges and desires of several people involved. Finally, we discuss the role of data in these processes and designs, the opportunities data provides to address current issues, and views, expectations and concerns interviewed experts have on this with regard to more interactive environment solutions.

2.3.1 Active Environments

What are Active Environments?

Invited to define “Active Environments”, our interviewees started with broad descriptors about the purpose of such places. For instance, an active environment “challenges you to move” (P2) or “invites and facilitates to become active or to get moving” (P3). Participants stated that active environments aim “to challenge users” (P2, P5, and P8), some preferred to use terms such as “invite or encourage” (P3, P4, P10, and P11) or even “seduce” (P8 and P9). Others adopted a stronger view, stating that active environments “provoke the desired behavior” (P9) or “ensure that you get more active” (P6). P9 notes additionally that technically one should use the term ‘*activating* environment’. Being easily accessible or close by was mentioned by several participants (P1, P5, and P7). Several participants associated active environments with the “outdoors” (P1, P6, P7, and P8). To define an active environment, P11 states that the “daily living environment should be structured in such a way that it strongly encourages you to exercise enough every day”.

From the preparation exercise, we collected 51 examples of active environments (Appendix B), ranging from specific elements or equipment to entire districts, and included both general examples and specific places or installations. We can divide the examples into aspects of DUS, aimed at integrating (more) physical activity into daily routines, e.g., active transport (n=26) and more dedicated physical activities such as sports and play, often with a recreational purpose (n=23). Two examples were classified as both: campsites and a suburban walking route network. The campsite is a recreational area that simultaneously represents an alternative daily living environment, requiring and inspiring much more physical activity than typical DUS. The walking route network is created for recreational purposes, but by providing attractive walking routes between destinations it also encourages active transport and provides green areas.

Participants agree that to some extent, this applies to most parks in urban areas: when destinations lie on both sides, the attractive connection through a park is likely to inspire active transport between those destinations. This effect becomes stronger when dedicated transportation routes (straight, direct routes with a suitable surface and proper width to accommodate the flow of foot- or bicycle traffic) are a part of the design. Comparing them to the key aspects of active environments found in the literature, we can categorize 13 examples as places for –or aspects of– active transport, 16 describe green or park settings and 19 examples represent mixed use and multifunctionality. Five examples were categorized as both supporting active transport and providing park or green areas. Eight examples represented places or equipment dedicated to specific recreational use.

Added value of active environments to encourage active behavior

According to our interviewees, the added value of intervening in the physical environment to encourage more active behavior can be seen at several levels. At a very basic level, the environment provides boundary conditions through the extent to which it facilitates active behavior (P4, P7, and P9). Using the public outdoor space for these facilities ensures accessibility for a wide range of users. It can provide these facilities in an *‘inviting and free’* (P4) manner, allowing people to decide for themselves if and how they use the provided space (P10). This element of ‘freedom’ to make autonomous decisions about active behavior is also mentioned by several experts as an important advantage of interventions in the public space. Experts highlight the distinct difference between 'active behavior' and 'sports' (P4, P7, P10, and P11), stressing that an active lifestyle only requires the first, not necessarily the latter. Focusing on creating more active daily routines therefore strengthens the potential of the environment to specifically also target and include the group that has (sub) consciously decided not to practice sports.

> *"I think [the added value of intervening in the physical environment] is substantial. [...] The living environment of people, you can achieve much more there than through stimulating sports" (P10)*

> *"I believe you can trigger and challenge –or facilitate– people more through a certain design." (P8)*

Interviewees also describe a certain inevitability of having to enter that environment, stating that *'using the space and therefore that space itself, is part of our identity'* (P11). Since people exist in context, the way their living environment is shaped largely determines their routines (P1). By designing and planning these places to make that desired behavior (such as walking or biking) easier or more attractive, the urban environment creates supportive daily urban systems (P1, P3, P8, and P9). These can be strong enablers to break bad routines and to create new, more active ones (P1). Especially for people in deprived areas this support to be active in the direct living environment is mentioned as very important (P7 and P10).

Creating Active Environments

Strategies

From our interviews, we can distinguish several strategies to evoke active behavior through environment design. Ranging from open and unobtrusive to increasingly more forced, these strategies can be placed on a continuum:

unobtrusive

nudge	*invite*	A very open and voluntary approach, associated with accessibility and openness
nudge	*seduce*	This approach draws people in by offering something so attractive or desirable it is hard to refuse
nudge	*challenge*	Presenting a challenge calls to people's competitive nature and their desire to find out if they can live up to the task
force	*create barriers*	The most intrusive approach creates barriers to hinder or even block undesired behaviors, leaving only the preferred option

obtrusive

Elements

Next to strategies, certain elements were mentioned that are important to establish active environments. These include design elements, but mostly focus on use of the space and creating a certain experience. Although divided into categories, many of these elements are closely related to each other through causality or overlapping effects, e.g., when the peaceful feeling of a green space is enhanced by its openness or quietness.

Multifunctional & adaptable

Most examples of active environments mentioned and many of the named elements are related to multifunctional or adaptable spaces. To serve a variety of people, diverse facilities are desired. These can be separate facilities, such as dedicated sports accommodations, but more effective are places that can serve multiple purposes, either at the same time or through varied use over time. This also helps to serve a variety in demographics and so broaden the target audience. Some examples of this include close indoor-outdoor relations, with large opening doors or other transitions enabling indoor and outdoor spaces to merge on occasion. Finally, to ensure long-term use, it is also important that the space anticipates user behavior, changing users and unknown factors, develops over time, or offers something worth coming back for.

Mobility & active transport

Frequently recurring throughout our interviews is an emphasis on active transport, as most physical activity comes not from deliberate exercise but from simply moving from place to place in an active manner (P11). Therefore, stimulating taking stairs instead of elevators, biking instead of driving, and designing places suitable for walking are likely to be most productive. This relates to mixed use areas on an urban scale, as different amenities must be distributed over a walkable or cyclable area.

> *"A central lunch area in the middle of campus creates a goal to walk towards. So, it's also: creating distance between the goals or destinations that people have. If you put everything next to each other, people will not cover much ground." (P4)*

Stimulating active transport through design can be done in several ways, but specifically cars appear to have a special status for users and therefore in urban designs. The comfort of easy transportation over well connected, wide roads with good traffic flow, and parking close to home is often perceived as essential. *"Often, cars have a kind of negative impact on the public space. And cars relatively take up a lot of space; many streets have turned into traffic spaces instead of living areas."* (P9). Several interviewed experts question this status quo (P5, P7, P9, and P11), wondering if, when focusing on healthier lifestyles and better environments, the car's prominent role should be reconsidered. Hidden parking, dead-end streets or 'bike streets', can remove cars from view and encourages traveling short distances by foot or bike. However, more progressive plans that for instance leave cars at the neighborhood edge, meet a lot of resistance from residents.

> *"We presented a fantastic mission about a healthy and movement friendly neighborhood, safe and pleasant for children, but the residents just wanted– they wanted all of that but not at the expense of their car." (P5)*

Attractive

Interviewed experts agree that attractiveness is an important factor. This is explained on the one hand as an aesthetically pleasing environment, with green or natural elements, things to see, sunken parking and enough space as frequently mentioned examples. On the other hand, it is also described as well programmed and conveniently located, with respect to infrastructure, orientation, and nearby facilities. This attractiveness can be used to invite or even seduce people to enter the environment and encourage active behavior.

> *"Many people walk and bike here because the street is so well designed, and it is just a pleasant place to be." (P9)*

Green, blue & outdoor

For some a synonym for 'attractive', outdoor, nature, green space and water are often mentioned elements. We see a link here to the desired experience of freedom and open space.

> *"It is appealing to walk a longer route back instead of the shortest option, just because it's a nice area where you walk through nature; there is a pond to walk around and all kinds of nice things to see." (P4)*

Social and lively

Next to physical aspects, the importance of the social context of active environments are mentioned by all interviewed experts. Liveliness and activity are also frequently discussed. Strengthened by multifunctionality and an important enabler for social attractiveness, liveliness is often mentioned as a key element of the desired experience. The provided social safety, social cohesion, and social contacts can help to attract people to a place or even to participate in certain activities, with social contacts and sporting or being active together as important motivators for physical activity. Additionally, seeing and therefore normalizing active behavior stimulates that same behavior in the spectator (P7).

> *"Seeing and being seen is very important. If you don't see it, you don't know it… While seeing [people being active], that also stimulates." (P11)*

Next to the strategy of creating *inviting* environments, social components can also be used to establish or enhance *challenge*, when people encourage and challenge each other to increase their performance. Finally, creating a sense of ownership of the public space will increase social safety and the feeling of being 'allowed to use' the space (P1 and P10). This can for instance be done by involving future users in the design process, a practice used by all interviewed experts.

Experiences

Although difficult to translate to direct design suggestions, a considerable number of statements about active environments contained feelings that such places should evoke. Especially joy, pleasure and happiness are frequently mentioned, along with freedom and space. Closely related to *attractive*, these statements stress the importance of creating amenity value, not just adding elements but also creating an experience.

Boundaries & thresholds

Within the scope of mentioned elements, we categorized some as threshold or boundary conditions. We regarded elements as such either when they are essential; without these, the place does not work.

Enable

Interviewed experts state that active behavior can be supported through either specific installations or a space that allows open use for several purposes. The environment provides the enablers to be active, so it is important that facilities address existing needs in the surrounding area. Especially opportunities to combine several recreation or transport facilities for different population groups in one place are deemed very effective. This is of course closely related to social, lively and multifunctionality elements, as multifunctional places bring groups together and so create a lively and well-used environment.

Accessibility

For practical reasons, accessibility is directly related to the effectiveness of active environments. Subdivided into reachability (access points and routes) and proximity, accessibility is an important enabler for use in general. Interviewees note that special attention could, and should, be paid to ensure accessibility for more vulnerable groups such as minorities, people with disabilities or low incomes. Additionally, proximity and visibility can enhance the see-and-be-seen aspect by enabling chance encounters with active behavior and environments.

> *"I like mountain biking, so then a forest path is very nice. But to get there I need to travel, often by train, so that always is something of a barrier for me." (P7)*

Safety

A sense of safety is necessary for any place to be considered pleasant or attractive, making this a clear boundary condition. Safety includes both social and physical safety, such as a suitable traffic situation, proper maintenance, lights after dark, and safe installations.

> *"If it's not safe –physically safe, socially safe– it can be the most beautiful and challenging place, but it will still not be used." (P8)*

Additional Challenges

We also asked participants about barriers and challenges regarding the use of the public space to increase physical activity. Part of the mentioned barriers are related to the active environment elements described above, such as the complexity of the venture, negative impact of unsafe places, physical barriers, or distance to facilities. We noted several additional challenges:

Participants agree that active environments depend on a delicate balance. *"With the physical environment alone, it will never work. To break routines, you need a hybrid, integrated strategy"* (P1). Even if most components seem ideal, *"when one of the other elements points the other way it can completely negate the rest"* (P8). Failing to provide the right socio-cultural context can weaken the effect of the physical conditions (P8). *"Presence of a bike lane does not automatically mean people will use it. You need to stimulate it and communicate"* (P3). It is important that the entire DUS is regarded, *"not just one piece of the puzzle"* (P9). The balance of active environments also depends on local and temporal factors, with changing variables for each place (P10) and over time (P9, and P11).

Another important question is how to prevent conflict of interest between different uses or users? For instance, when playing children use the same space cars use to 'kiss and ride'(P5) or when a growing population and increased recreational use of the quay forces rowers out of their training zone (P11). Such situations are ideally recognized early in the design process so that a suitable compromise can be found. A popular strategy to address as many relevant elements as possible is including user input in the design process, often through a form of co-design. All participants agree this is effective and have used such methods in the past. However, *"when users are involved they will quickly start to serve their own interests, which do not always align with an active living environment"* (P5).

While the presence of green space is often mentioned as an enabler of physical activity, there are also some critical notes. Green is also a *'distance-creator'* (P10). This does not always align with the desired accessibility or liveliness of destinations that also encourage physical activity. It can even decrease perceived safety. Additionally, *"more green space does not lead to more physical activity, there is no relation. There is, however, for* attractive *green"* (P11). Another potential disadvantage of more green space is that as it creates distance, it also creates more space to park cars, which in turn leads to increased car use (P10).

Related to the social aspect, when creating active environments it is important to consider whether the activity in question is socially accepted for people to feel comfortable doing it (P4, P5, and P11). Finally, P4 points out that it is difficult to measure effects in a robust way, because when using sensors or tracking there should be consent or an opt-out for participants.

2.3.2 Process

The process of creating active environments is described as a complex and often long-term process by our interviewees and in the literature [51,248]. Based on experiences and descriptions of interviewed experts, we provide insight into two main factors responsible for this complexity – the timeline and multiple stakeholders– what this means for monitoring and evaluation, and other related challenges that project teams experience.

Timeline

Although there is ample variation, largely based on scale, active environment projects are essentially urban design projects and therefore typically measured in years, sometimes decades. Related to the scale and public nature, the large number of involved stakeholders also results in a slower process.

The discussed example projects ranged from six months for a public beach volleyball field (from the moment 'the right people were involved' (P3)), in which design, management and construction were realized, to over fifteen years for an urban redesign, subdivided into five years of research, strategy development and a first version urban plan; five years of user participation and iterative redesign; and five years from urban plan to construction plans. This still excludes the actual construction phase.

A longer run time leads to more complexity because over time, team members, vision, demands, and policies can change, often leading to reassessment and adjustments. Regarding this timeframe, the design will be built largely on foresight and predictions of future users, which require more research and advanced strategies. Additions to or interventions in an 'existing' environment are much smaller, with a more straightforward and faster process than a complete area redesign.

> *"The more large-scale, the more complex and long-term." (P1)*

We note that with their varying positions and roles in the process of creating active environments, the interviewed experts do not all define the same 'starting point' of that process when they discussed timeframes. This was mostly related to their own involvement. Some defined the 'start' as the moment an idea was defined, and for others, it started when the money was made available or when the project team was assembled.

Stakeholders

Complexity also comes from the number of stakeholders in active environment projects. While again increasing with project scale, even for a small project there are many to consider. With varying stakes, concerns, opinions, and degrees of influence for all involved, who all need to come to an agreement, more stakeholders inevitably lead to a more complex process. We have defined six types of stakeholders that are involved in all active environment projects:

- Client and investors: often (local) government or project developer, occasionally company or private party
- Property owners: government, housing association, company, or private party
- Creators: designers (urban planners, architects, landscape designers), developers, builders, and contractors
- Rules and regulations: government (a.o. spatial planning, public health), spatial management, security
- Research and information: research partners & institutions, data analysts, knowledge institutions, municipal health service, consultants
- Users and involved parties: residents; local entrepreneurs, schools, or institutions; housing and community associations

Monitoring & evaluation

Though it concerns expensive and long-lasting projects, all interviewed experts agreed that there is very little monitoring or evaluation of projects after realization and post-occupancy. While often aiming for a 'better' or 'more active' living environment in general, the defined project goals do not reflect measurable standards to determine whether the project has succeeded in reaching this goal. Though they all acknowledge the desire for this validation and the knowledge it would bring, interviewees also list many reasons explaining its absence.

Very pragmatically, it is often 'no-one's job' to do this research, leading to the question of who should. Designers leave the project once construction starts, moving on to the next project. The same goes for builders after construction. Adding research time is not part of their contract. Since validating post-occupancy success is not required, there is also little incentive for investors to fund this.

Another much cited issue with post-occupancy validation is the large number of variables involved, causing an ever-changing context with accompanying challenges of measurable goal setting. What goals can be set that represent a 'better' or 'more active' living environment and can at the same time be expressed in measurable aspects? To what degree can you compare pre- and post-intervention situations if there are different people, different weather, different activities or other variables that cannot be controlled? *"This dependency on uncontrollables makes it so hard to define proper validation criteria that it is only rarely tried"* (P5). These comparison issues only get worse when more time passes between the pre- and post-measurements.

Related to this, it is also debatable to which extent success or failure features at one location will be the same for another. Different contexts with many uncontrollable variables make comparing two places a challenging endeavor. This in turn increases doubt about the value of such research.

> *"If you design and organize the suburbs of Amsterdam the same way as the city center, the first thing that will happen is that the residents will leave. Because that is not their environment." (P10)*

An obvious counter to that doubt would be for general research purposes, at least. After all, if enough data of enough projects is collected, general statements and truths can be derived on an abstract level that apply to most, if not all, projects. This would require a critical mass of studied interventions before producing useful insights, but for research institutions, such large-scale and long-term studies are far from unheard of. However, current research projects related to healthy and active environments are often validated based on valuable lessons learned, publications or clear process descriptions, regardless of the effectivity of the designed space itself (P1). Again, this decreases incentive for that validation.

2.3.3 Data

Data in the current process

For most interviewed experts, the role of data is limited to mapping pre-intervention situations and, sporadically, evaluating the new, post-intervention one. To get a comprehensive view of the 'current' (pre-intervention) situation, data is collected on a wide range of contextual and user-specific topics. Often, a combination of qualitative and quantitative methods is used, including surveys, interviews, diaries, counting, tracking devices, and focus groups. The most frequently mentioned collected data types are demographics, socioeconomics, neighborhood and behavior data, long-term statistics, and health parameters.

Within the context of creating healthy active places, these data mostly provide information about behavior, health and wellbeing of the local population and the current state of the environment (including green- and traffic infrastructures, facilities, and programming). Important to note is that not all these data are collected by the project team. Especially generic, large scale and long-term data typically comes from local or national databases built from routine population screening. For these data, the project team is dependent on available data, which is often less copious for smaller and sparsely populated areas (P9 and P10).

Several experts (n=5) also include a (local) needs assessment in their sum-up of collected data, which was used to finalize problem definition and design directions. For others, this was already established by other parties or before they were involved in the process. For long-term processes, such as urban redesign, additional input from users and other stakeholders was collected at certain stages in the process to realign or adjust course if needed.

Data Desires

When rounding up the illustrative example, we asked participants what could have improved the process or what they desire for future projects. All experts expressed a desire for more data for better monitoring and evaluation (P1, P5, and P7), learning behavior patterns and motivation (P1, P2, P3, P4, and P9), problem definition or hotspot finding (P3), walking routes (P4), information about future users (P5), crime rates (P7) and more and longitudinal post-occupancy data collection (P1). P7 further specified a need for better ways to predict user behavior and deal with changing needs over time. Some participants also preferred clearer instructions to interpret the accessible data (P11 and P8) and visualizations instead of 'numbers' to provide data insights in a comprehensive and instinctive manner (P6 and P8).

There is a clear desire to bring together and combine knowledge that exists in different places (P2, P5, P8, P9, and P11), which requires a more integral approach with experts in different fields (P9, P11) and a back and forth between them during the process, instead of one waiting for the other to finish and then take over (P11). In line with the need for more data and more knowledge about data-handling, several participants desired a stronger collaboration between knowledge or research institutions and practice (P1, P5, P8, and P11). For instance, for monitoring of effectivity (P5), or shared use of resources (P8). Finally, P1 expresses a desire for comprehensive modelling to create a 'digital twin' of the design before realization to test scenarios. This would create a feedback loop in the design process, making it more iterative.

> *"Ideally, data is in the full cycle of analysis, scenario development and optimization, definite plan, monitoring impact after realization, assessing, and optimizing for redevelopment of the environment. Perhaps the first is happening –although I am pretty sure not systematically and comprehensively– the rest is not." (P1)*

Interactivity and creative use of data

We also asked participants about their expectations regarding application of more interactive technologies to create active environments. We divide their answers into two categories: concerns expressed and possibilities seen.

Barriers & concerns

We note that besides the data designers, participants have some difficulty in imagining what such technology could add, because they find it hard to envision suitable application examples. They associate the terms 'data', 'technology' and especially 'interaction' with collecting data (P1, P4, and P11), commercialization of the public space (P5), fun-for-once gadgets (P9) or interactive play installations for children (P8). This may be nice for some finetuning (P9 and P10) but it is not essential to improve active environments (P9, P10, and P11).

> *"Multifunctionality in the physical sense, I totally get that. [It can have different functions at different times, based on] the physical appearance. But a digital layer, how that can contribute– I'm still unsure what that would be exactly. But exciting." (P9)*

When discussing personalization, experts expressed concerns about privacy (P4, P5, and P6), and whether thorough personalization could be perceived as 'scary' (P6). They also worry about feasibility and desirability of personalization of the public space (P1 and P2); the added complexity and necessity to use an accompanying smartphone app (P8). Some experts also feel that interaction or personalization often remains too shallow (P4, P6, and P9), making it cheesy (P6), boring (P9) or patronizing (P4). P1 additionally wonders if it is desirable from a social perspective, since one of the goals of the public space is to bring people together. People should therefore not only use it in a personalized way, but together.

Finally, some practical concerns are raised, such as costs and maintenance, durability (P8 and P9), sustainability (P9) and who is responsible, both for maintenance and for data collection and security.

Data opportunities

All participants saw potential for smart solutions to improve measuring, monitoring and knowledge acquisition. Some further specified this as large-scale data collection to learn about real behavior patterns over time and gain more in-depth understanding (P1 and P2). Participants also mentioned opportunities for combining data (P5 and P6), creating predictive models (P6), providing overview to help deal with complexity (P7 and P8) and to improve problem definition (P3, P9, and P10).

When thinking of actual interactive applications, some imagine hybrid solutions with a digital layer placed over the physical world (P8), creating a deeper connection between the physical and virtual world (P9), which enables different use of the physical space (P9). Participants see use for such technology to reach higher levels of personalization (P3, P6, and P7) based on certain personal preferences (P7), depending on life phase or age (P6), or even establish several layers ranging from the individual to a larger whole (P4). They also see opportunities to increase efficiency –e.g., smart transport systems (P10) or energy use (P7) and encouraging active transport through smart green light solutions for bikers and pedestrians (P3) –; automatization of processes (P4); and improving sustainability (P5), safety (P7) or health related parameters (P10).

2.4 Discussion

In this study, we investigated the process of designing and implementing active urban environments through semi-structured interviews with 11 experts in this field. When selecting participants, we aimed for diversity and multiple perspectives. Views or methods that seem field-specific may therefore be influenced by personal vision. Though outside the scope of this chapter, it would be interesting to regard different perspectives between disciplines on a larger scale. Future studies could also include experts from other regions of the world next to Europe to refine the global vision and further expand applicability of their findings.

We identified several aspects of active environments: associations and definitions, design process and guidelines, impact on user behavior, and the process of realizing such environments in the public space. Regarding active environment examples provided by interviewees, we note some professional bias, as larger area examples come from urbanists and digital installations are mostly named by participants with an industrial design background. Several examples concerned projects that participants had worked on themselves. Despite this, the sample still provides insights into what professionals perceive as active environments. The diversity of examples indicates variance in definitions or participants' associations with such places. This ambiguity aligns with different terminology used throughout the literature, suggesting lack of a universal definition of active environments, their scale and/or context. Combining definitions provided in the literature with those given by participants, we define active environments as physical places, typically in an urban context, that through their function and design increase physical activity levels of their users.

We compared 51 active environment examples provided by interviewees to determinants of the built environment associated with physical activity found in the literature. We see a clear overlap in important themes between the literature and these associations. However, where the literature focuses on active transport as the main determinant [90,186], these examples show stronger affinity with green places, multifunctional and mixed-use environments. While proximity to different destinations increases walkability and therefore also supports active transport, these diverging points of focus suggest a disparate emphasis in research and practice. Whether this difference stems indeed from vintage point or rather from more practical considerations –such as active transport being easier to measure and therefore research than for instance the impact of mixed-use or multifunctional spaces– is not clear.

To compare the practitioners' lens to theory from the literature, we discussed definitions and important elements of active environments in our interviews. We combined and organized these into five themes, desired experiences and three boundary conditions. Especially the design elements mentioned here are in line with goals and guidelines for active environment design found in the literature [186]. Though we see a lot of overlapping and complementing elements indicated as important for active environments, there are also some noticeable differences. For instance, interviewed experts describe both green, open, and quiet places and lively, multifunctional urban hubs as typical examples of active environments. This underlines the varying activities, experiences, and desires they associate with 'being active'. Based on these interviews, physical activity can be perceived as a mindful experience, focusing on bodily tasks and attractive surroundings. However, it also has the potential to bring people together, creating a lively environment and thus become a catalyst for social structures and cohesion. People are attracted to such social hubs for companionship and sense of belonging. The social component of active behavior is a strong motivator for physical activity and therefore of great value for active environments. When brought together through active behavior, people are simultaneously motivated to join the action through normalization, invitation, challenge, or positive peer pressure. Sense of belonging and 'see and be seen' are main motivators for people in general and thus also for active behavior. It is important for active environment designers to address all these purposes of and motivations for physical activity.

Creating active environments is a complex process, as it is often long-term and concerns multiple stakeholders. Despite the added complexity, involving all stakeholders in this process yields key goals and principles that help shape successful active environments. This includes consulting future users, a popular strategy that is both used and recommended by all interviewed experts. As there are many approaches to this, often depending on project specifics, details about user participation in practice are outside the scope of this chapter.

To improve the design and/or creation process of active environments, participants agreed that studies of design processes combined with evaluations of long-term use and impact of realized projects would be valuable. However, since these projects are typically initiated and executed by local governments and developers, evaluation is simply not a priority. Even if developed by or with a research team –e.g., in cooperation with a university– there still rarely are studies of eventual impact or effectivity [278,281]. This is a big gap and a missed opportunity to learn from both good and bad previous work.

The existence of this gap was already addressed by Frumkin in 2003 [108] and O'Neill and Simard in 2006 [232]. Sadly, little seems to have changed in the following fifteen years, as experts still list mostly the same issues described by them; *What should be evaluated? Evaluate for who? Who should undertake the evaluation? How should the evaluation be performed?* [232]. All these topics were addressed during our interviews, stressing the need for a better framework to perform this evaluation, or perhaps more rigorously to discard the desire for a 'checklist' and develop a method suitable for this complex, long-term process.

We see potential for this in new data applications and smart city technologies. When asked what could help improve the process or designs of active environments, participants all agreed that more knowledge –coming from more data– would be helpful in a variety of ways. Using embedded sensors or other smart technology, many previously unattainable data are now within reach and should be used to their full potential. To capitalize on the opportunities provided, participants argue for stronger collaboration between knowledge institutions and practice as well as for adding data experts to the project team.

Advanced data analytics methods can help track and understand behavior longitudinally and on a large scale. Embedding more technology into the environment makes it less static, perhaps even interactive [306]. A digital layer allows for easier adjustments, increasing multifunctionality, a main element of active environments mentioned in these interviews. Such environments can also be more easily altered –or updated– once they are realized. This allows for a more iterative urban design process, where the data collected by an environment actually feeds back into the design loop to improve that very environment. We thus conclude that data can be used for more than collecting information about use and performance. It can become a creative material for designing engaging interactions and intelligent ecosystems [160]. When regarded as such, data may become an integral part of a new generation of interactive environments [266]. Although we are excited by the opportunities this presents, Further research is needed to explore the potential of interactive solutions for active environment design. Smart city and human-environment interaction developments underline the value of expanding the multidisciplinarity of design teams to increase insights gained from available data. We see an opportunity to include not only data analysts but also data designers in these teams.

2.5 Conclusion

In this chapter, we discussed definitions of Active Environments and their added value in the public space when aiming to increase physical activity of a population. We first presented an overview of the strategies and elements used to create them. We then provided insights into the complex process of realizing such environments by describing the two main factors responsible for this complexity: the timeline and multiple stakeholders. We reviewed the challenges that occur, paying special attention to monitoring and evaluation. Finally, we discussed the role of data in these designs and processes, and opportunities it provides for both researchers and practitioners. With this work, we contribute to closing the gap between theory and practice by bringing together insights from both. By outlining key elements of the design and realization process of active environments together with issues, desires and potential identified by experts, we provide valuable insights and inspiration for professionals on both sides.

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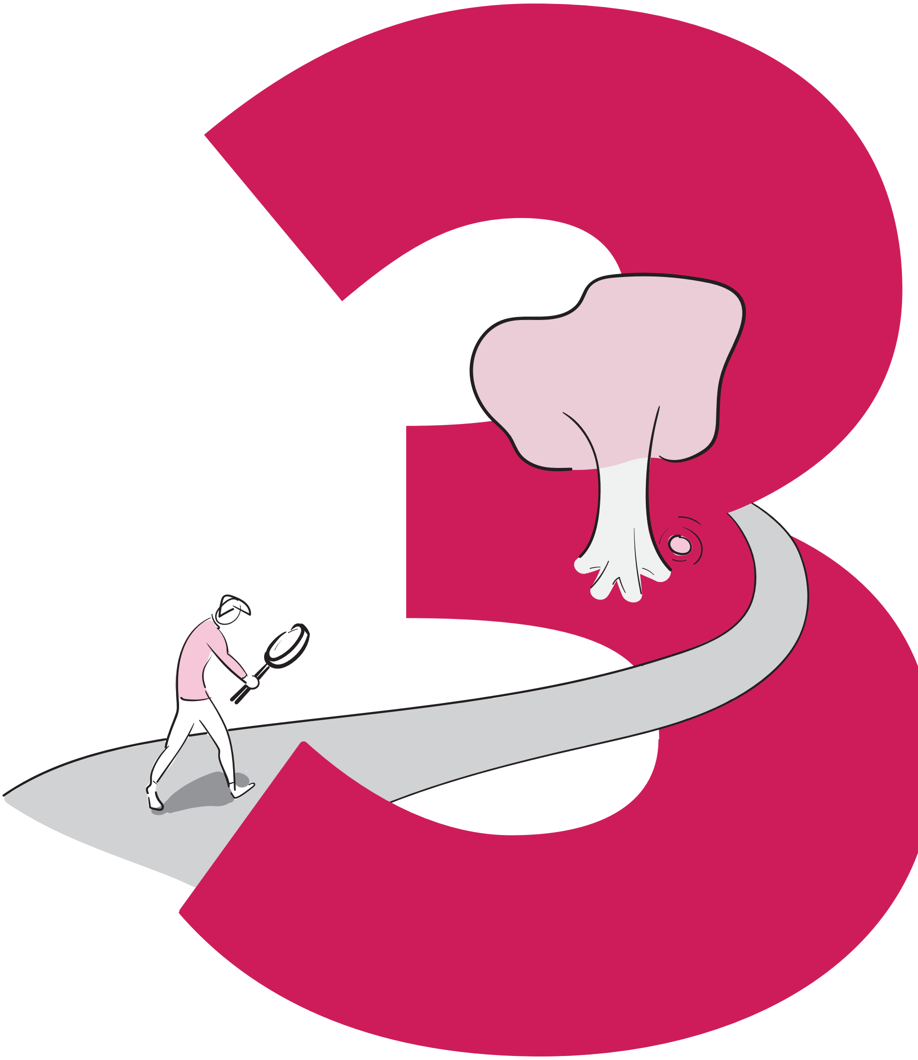
part II

Toward interActive Environments

In the first part of this dissertation, we described how the design of active urban environments can become an effective medium to nudge people into moving. With technology increasingly integrated into our daily lives, designers have access to ever advancing technologies. In this part, we investigate how integration of data and (interactive) technology can enhance the positive effects of active environments. As these places are designed to increase the physical activity of their users or passers-by through the use of interactive technology, we call them interActive environments. We start by exploring the design space of such solutions in chapter 3. Through sketches, a benchmark of existing concepts and an analysis of designed artefacts, we map the different intervention levels, interaction modalities, behavior change strategies, and technological opportunities to design interActive environments. We then further examine several of these concepts through four design case studies. For all these cases, we describe the interaction modalities, strategies, and technologies used as well as the findings of in-the-field user testing.

In chapter 4, we focus on aspects that positively impact motivation and/or performance: personalization, goal setting, and feedback mechanisms. For this, we created Guided by Lights, a walking and running path consisting of LED tiles in a public park that supports runners or walkers to set personal goals and gain intrinsic motivation to be physically active by offering guidance through light feedback. In chapter 5, we encourage physical activity by focusing on improving the exercise experience, with running as an example of a popular outdoor activity. As the desired experience of running in nature is often unattainable for runners in urban environments, we designed Sensation. Sensation is a sonified running track that senses the footsteps of runners. It uses audio feedback to augment the urban landscape and enhance the positive feelings people experience during a run. With Sensation we research the effect of using sonifcation through a physical, environmentally embedded design on the running experience. In chapter 6, we look into lowering barriers to active behavior as well as improving the experience, by reinforcing existing active behavior and triggering exploration. For this, we designed Discov, a network of physical waypoints that stimulate people to lengthen their walks. Placed in a public park, Discov encourages people to explore their surroundings in a fun and challenging way by creating an interactive walking experience. With Discov, we explore the potential of the design of accessible infrastructures and human-environment interactions to impact public health by nudging people into being more physically active. In chapter 7, we use water as a fun and connecting element between users, further expanding the accessible nature of interActive environments by using inclusive design principles. For this, we designed Fontana; an interactive water installation that invites different users to work together. Through Fontana, we explore how such installations in the public space can nudge people into an active behavior while strengthening social connectedness and remaining accessible, using the multidimensional attractiveness of water.



Exploring the Design Space of InterActive Urban Environments

Triggering Physical Activity through Embedded Technology

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3.1 Introduction

Physical inactivity and the resulting health concerns are a key societal challenge in modern western societies [33,159,334]. Promoting healthy and active lifestyles is thus a timely topic for public policies as well as across multiple research fields. In this pictorial, we address physical inactivity specifically, which is influenced by a combination of individual, social and environmental factors [122,134]. Design of 'activating' urban environments can be an effective trigger to subconsciously nudge people into moving [167,275]. Within the design community, we see opportunities in the field of active environment design [90,166], as well as in the ongoing shift towards Human-Environment Interaction (HEI) [297,306], where technology is increasingly integrated in the environment and is therefore omnipresent while less noticeable. These smart environments also allow for new types of feedback [297], and new levels of personalization of the environment, also an important factor in persuasive technology [28].

In this chapter, we explore the design space of interActive environments, which we define as interactive environments that encourage physically activity behaviors, focusing on three aspects: the interaction modality, the intervention strategy and the technology used. Through our research, we investigate the potential of embedding interaction into the environment to engage a broad audience of users, including those who did not consciously decide to work out or download an activity app. Therefore, these 'accidental' encounters can broaden the impact of design interventions for physical activity, by involving a hard to reach but important target group. A number of commercial solutions, public installations and exploratory prototypes that use technology in the outdoor environment as a trigger for physical activity have been designed, but to the best of our knowledge these efforts have yet not been drawn together or analyzed on a broader scale. The presented design space exploration combines the results of a (1) benchmark of existing active environments, partly based on expert interviews, (2) sketching explorations with industrial design researchers and students, and (3) four use case analyses. This illustrated analysis of the design space of interActive environments is meant to inspire researchers and designers, and to pave the way for new designs and applications, optimizing the role of technology to shape meaningful experiences.

3.2 Benchmark

We started our design space exploration by benchmarking existing interActive environments, places purposely designed to increase the physical activity of users or passers-by through the use of interactive technology. In addition, we conducted semi-structured interviews with 11 professionals involved in the design of interActive environments. We purposely combined perspectives from different disciplines, including industrial designers (n= 4), architects and urban planners (n=3), policy makers (n=4), some of them being also design researchers. In addition to our own benchmark, we asked each of these experts to provide us with typical examples of active urban environments, ideally including an interactive/ technological component. These examples were discussed during the interview to understand what characteristics made them suitable to be described as active environments, which strategies were used to trigger people to be more active, what were the gaps in the design space especially related to the use of technology and data, and the underlying challenges for future development in this area.

Out of our scope are the numerous active environments which do not make use of technology (e.g., healthy routes, bare foot paths, walking meeting routes), rely solely on mobile technology without any intervention in the physical environment, as well as installations that specifically target children (e.g., smart playground design).

Smartphone apps that use the physical environment [Figure 3.1] in the context of sports training (e.g., visualizing one's running route) or location-based exergames (e.g. Pokémon GO [228]) gained popularity in the last decade. While these make use of the physical environment (e.g., PokéStops in Pokémon GO are located on points of interest in the real world) or even augment it using Augmented Reality, they are not in the scope of interActive environments as no actual artefact nor technology is placed in the real world. Playground design increasingly make use of technological components in order to promote cognitive, social and motor skills development [83]. While these outdoor play technologies might be relevant to consider, we narrowed our scope down to design concepts not targeted at this specific children audience.

Our benchmark allows us to distinguish several categories of designs, illustrated and annotated in the following pages: public recreational sports environments, temporary high-tech sports facilities, interactive public installations and active office environments. Noteworthy, we also found an important number of student and research projects conducted at design universities within interaction design or interactive environments curriculums. These numerous prototypes, while showcasing innovative properties, however remain at a conceptual stage, and are usually not deployed nor implemented in the public space. Benchmarking existing designs is worthwhile to understand success factors, challenges or limitations, as well as identifying the gaps and future design opportunities.

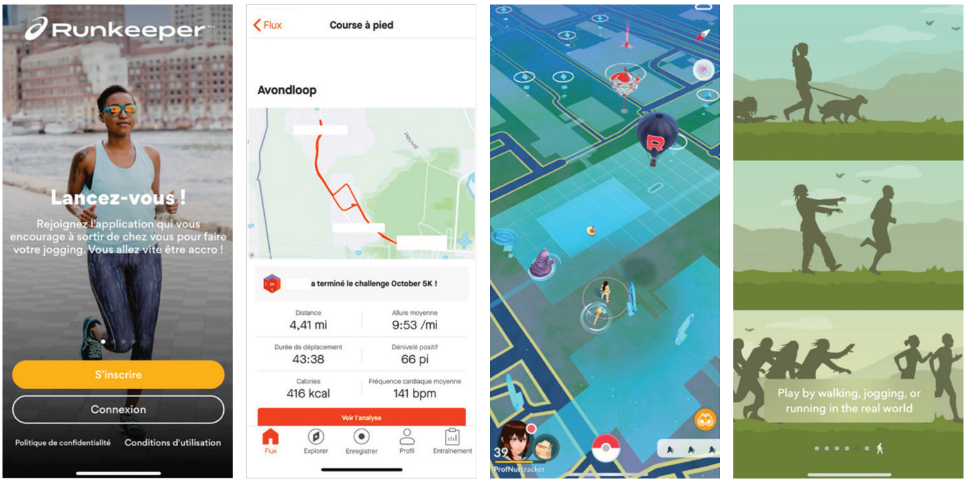


Figure 3.1: Smartphone applications associated with physical activity and connected to the physical environment. fltr: Runkeeper [101], Strava [297], Pokémon Go [224] and Zombies, Run! [290]

3.3 Benchmark on interActive Environments

3.3.1 Public recreational sport environments

Environments targeted at recreational sporters/runners are often located in public parks and green urban areas or on sports fields. These designs are usually composed of modular elements, robustly integrated in the environment in order to resist weather conditions, intensive outdoor use and sometimes vandalism. Some running track equipment designers started offering interactive features supporting training, mostly focused on athletic performance or serving accessibility purposes.

Run!

Run! [204] is a High-tech running track along a popular public running route. Through an adaptive light system it stimulates a more intense training and inspires (more) people to exercise.

Figure 3.2: Run!

Smart Exercise Route

The Slimme Beweegroute ('Smart Exercise Route') [76] is a 1.8 km walking and running path consisting of LED tiles in a public park.

Figure 3.3: Smart Exercise Route.

Figure 3.4: #WaveLight.

#WaveLight

#WaveLight [329] is an electronic pace-setter guiding runners on time, speed and interval. Easy to install on existing and new athletics tracks, it comprises of 400 LED lights placed in the drainage covers.

3.3.2 Temporary high-tech sport facilities

Temporary high-tech facilities target athletes and often act as marketing events for international sports brands. These innovative pop-up environments make impressive use of technology, combining multiple sensors, and providing a unique user experience mainly focused on performance.

Nike Unlimited Stadium

Nike Unlimited Stadium [25], described as the world most innovative training environment, tracks a runner's lap time using hyper-accurate Radio-frequency identification. The next lap, your avatar appears, running your previous time to beat. It thus challenges you to keep bettering your best.

Nike Rise House of Mamba

House of Mamba [5] is a full-sized LED basketball court for the NIKE RISE basketball tour which took place across China. It utilizes motion-tracking and reactive LED visualization to train and challenge the players through authentic drills based on Kobe Bryant's training.

3.3.3 Active Outdoor Office Infrastructure

Active office environments are designs located in the surroundings of office buildings, with the intention to trigger physically active ways of working.

The Hubs

Along a route for walking meetings, a network of Hubs [78] supports work-related tasks such as presenting and notetaking. The Hubs facilitate this type of physically active meeting practice by gaining social acceptance within the organizational culture and overcoming obstacles related to walking meetings [79].

Figure 3.5: Nike Unlimited Stadium (image courtesy of BBH Singapore & Nike).

Figure 3.6: Nike Rise House of Mamba (image courtesy of AKQA & Nike).

Figure 3.7: The Hubs.

3.3.4 Interactive Public Installations

Interactive public installations are the most common type of interactive environments in the public space. Targeted at a wide audience, they often rely on principles of fun and gamification. Several of these projects (e.g., Piano Stairs [311], Musical Swings [74], Urbanimals [176]) are gaining public recognition through design awards. They are usually ephemeral and "on tour" in different cities. Reflecting on their transformative qualities, it appears that their user experience primarily relies on a novelty and stimulation factor, which might fade away across time.

Piano Stairs

The iconic Piano Stairs project by the Fun Theory (2009) in Stockholm, Sweden [311] nudges people into taking the stairs rather than the escalator.

Stride

Stride [172] is a student project composed of a forest of poles, featuring interactive stepping stones. When pressure is detected on a stone, the step lights up and plays a sound.

Urbanimals

These interactive projected animals by LAX [176] encourage to explore the city and play with them, invoking activeness and creativity.

Musical Swings & the Pearl Divers

Musical Swings [74] and the Pearl Divers [75] are interactive installations, designed by Daily Tous les Jours, which invite passerby to make music together with their entire bodies. They represent an emergent field of practice combining technology, storytelling, performance and placemaking.

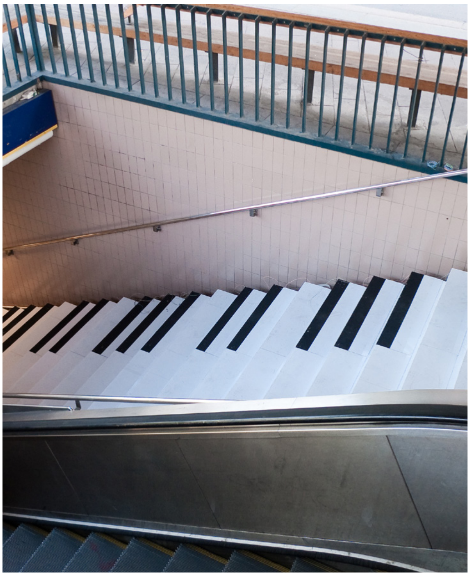


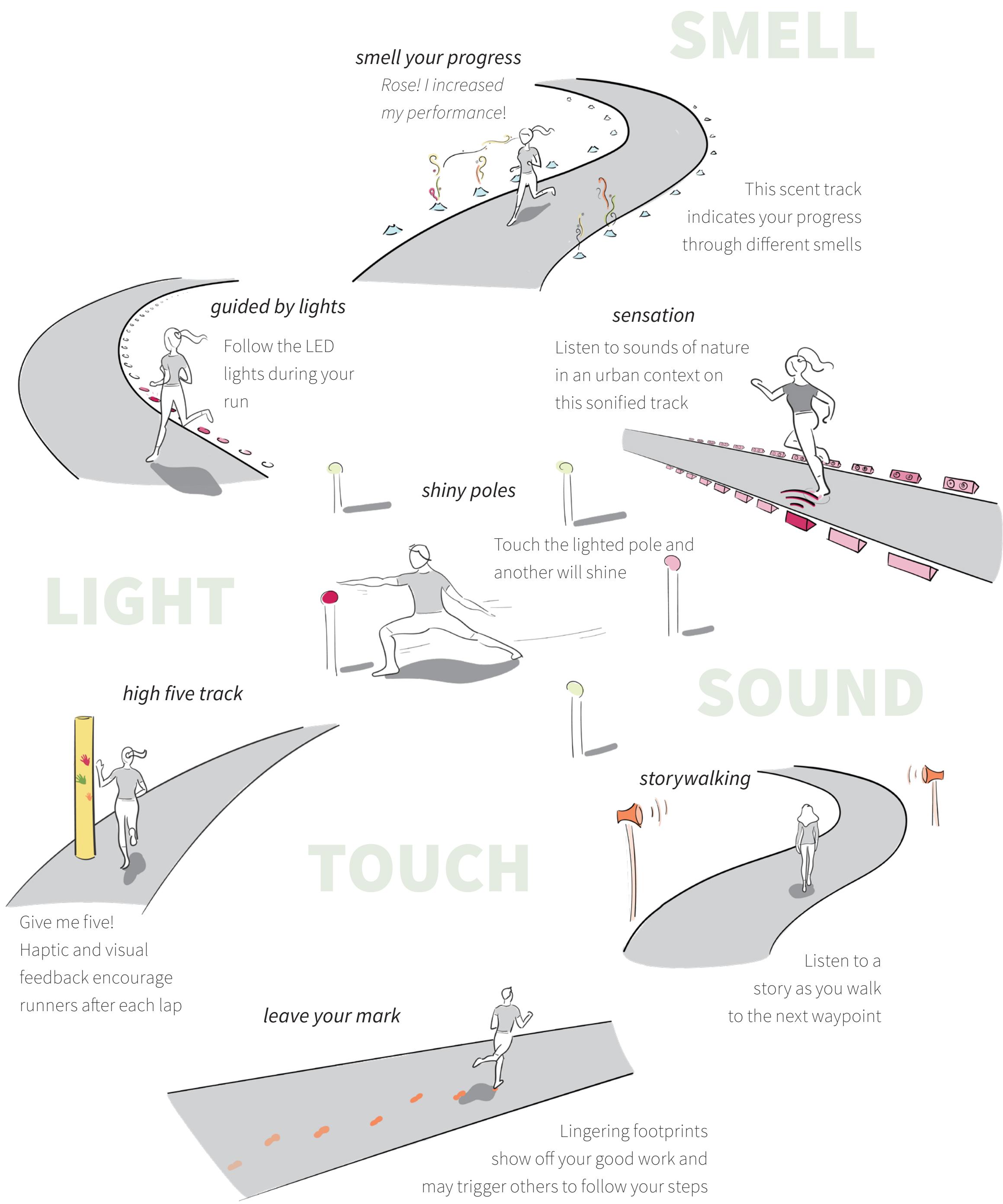
Figure 3.8: Piano Stairs.

Figure 3.9: Stride.

Figure 3.10: Urbanimals.

Figure 3.11: The Pearl Divers.

Figure 3.12: Musical Swings.



SMELL
smell your progress
Rose! I increased my performance!
This scent track indicates your progress through different smells
guided by lights
Follow the LED lights during your run
sensation
Listen to sounds of nature in an urban context on this sonified track
shiny poles
Touch the lighted pole and another will shine
LIGHT
SOUND
high five track
storywalking
TOUCH
Give me five! Haptic and visual feedback encourage runners after each lap
Listen to a story as you walk to the next waypoint
leave your mark
Lingering footprints show off your good work and may trigger others to follow your steps

3.4 Design Explorations

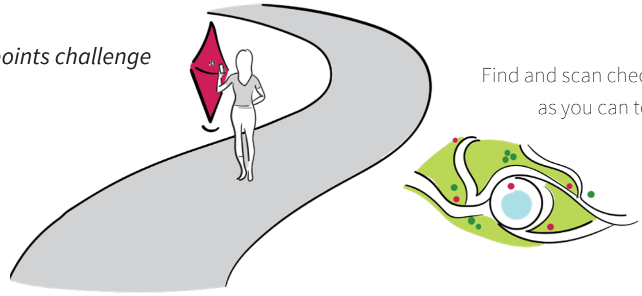
The second part of our design space exploration focused on ideation and sketches of interActive environments, mostly related to walking and running in urban environments, based on literature and design research and explorations from Industrial Design students and researchers' projects over the last two years. As this design activity was exploratory in nature, aimed at mapping out the design space of interActive environments, most of these concepts remained at the conceptualization stage and a selection only was further developed into prototypes (see Design cases). Reflecting back, we used affinity diagramming to classify the sketches into themes (see also Figure 3.22, p.12) and share the insights we gained from these explorations. Illustrative examples are depicted, some overlapping between several levels of analysis. Further reflections on domains not represented in the sketches are suggested.

3.4.1 Interaction Modality

We first can distinguish several channels of sensory input/output between the environment and the user. The most common interaction modalities were the use of auditory and visual feedback. In line with its predominance in the benchmark, light (using LEDs) tends to be the first idea coming to the mind of designers. It is undeniably a relevant and less intrusive type of feedback in outdoor environments, as compared to sound or smell, but often less visible on a bright day. In our sketches, sound is explored in relation to storytelling, mindfulness and music, which is a common element in recreational running [139], as well as for motivation and guidance. In the storywalking concept for instance, you would listen to a story as you walk to the next waypoint. While being a popular modality used in running-related smartphone apps or in the practice of runners simply listening to their favorite playlist, sound seems rarely encountered in interActive environments. Of course, it is a somewhat disturbing modality in the public space, which could cause nuisances or privacy concerns. Yet there might be intriguing opportunities there too: sound attracts attention, creates a specific ambiance and might stimulate social exchanges and shared user experiences.

Haptic feedback is used to augment the experience or bring a fun element to it. Way less common is the use of smell, only present in a couple of sketches where the designers forced themselves to explore all human senses. The 'smell your progress' concept for instance suggests using a variety of scents to represent success and performance. Olfactory feedback, while interesting, currently seems challenging to achieve in outdoor environments and might even compete with natural pleasant scents (e.g., freshly cut grass, rain, forest). Designers might get inspired by the use of scents in the field of marketing and retail, where numerous investigations have been made on how it impacts consumer experiences and nudges them into buying behaviors. Translated to the exercising area, one could attract walkers or runners to the next milestone by the use of smell, just like bakeries attract consumers with the irresistible smell of freshly baked bread or pastries. The last of our five senses, taste, was considered yet remained absent from the sketches collected. Rare examples of designs in the field of sports make use of this modality, as Tasty Beats [153] or Edipulse (turning physical activity into chocolates) [154]. Finally, designers of interActive environments can also make use of senses related to the vestibular system, such as gravity, movement and balance.

waypoints challenge

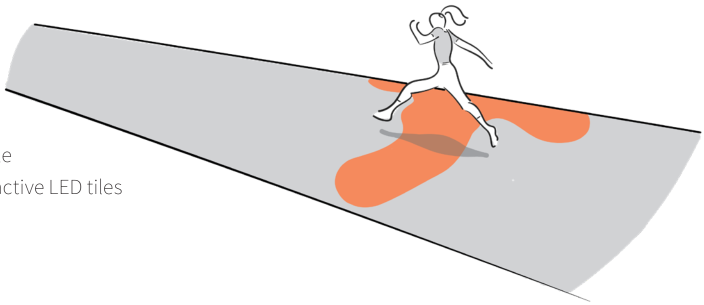


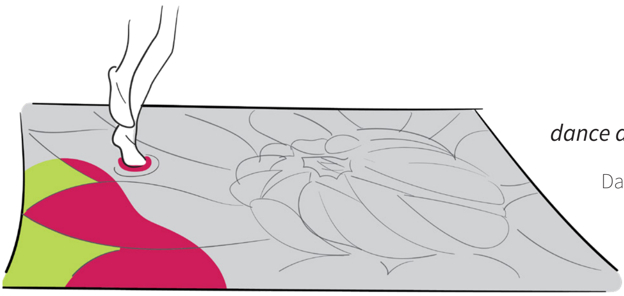
Find and scan checkpoints as fast as you can to collect points

FUN

the floor is lava

An exciting obstacle course using interactive LED tiles





dance an artwork

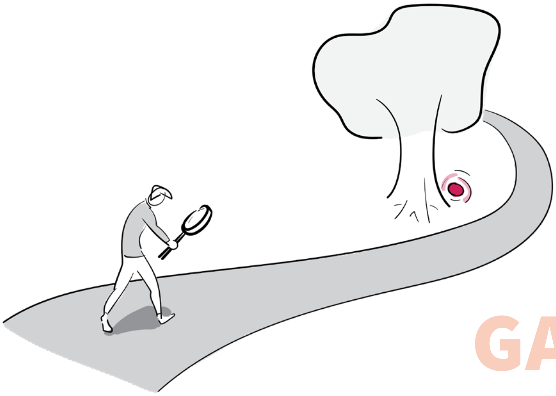
Dance to add color to this artwork, an interactive mandala coloring experience

3.4.2 Intervention Strategy

Designed environments make use of various intervention strategies, in order to create a positive experience or to trigger behavior change and nudge people into moving.

Fun / Gamification

The most common explored strategy was the use of fun or gamified elements. Considering recreational sport as a leisure activity, these concepts highlight ways to use interactive technology to design playful experiences. Some concepts include challenges in order to stimulate exploration of the environment (e.g., waypoints challenge or photo challenge, where's Waldo?), while others link the activity to charitable causes (e.g. making a donation) potentially during pop-up sponsored events. Other concepts were directly inspired by popular games, such as 'the floor is lava' or 'where's Waldo?'. Finally some more stationary (as in, located at a single place in the urban park)



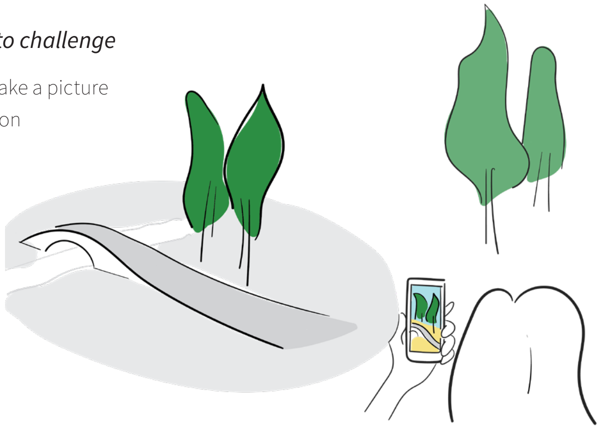
where's Waldo?

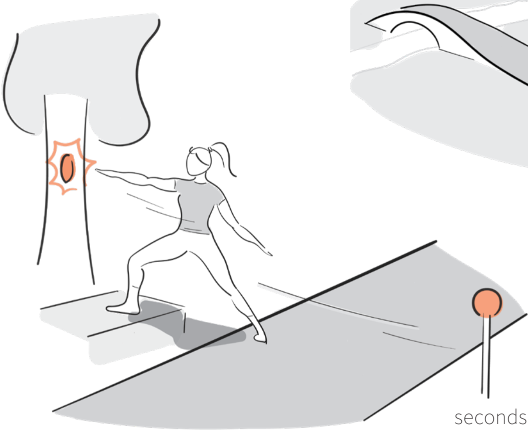
find and follow Waldo in the park!

GAMIFICATION

photo challenge

Find the element represented, take a picture and validate via image recognition





donation buttons

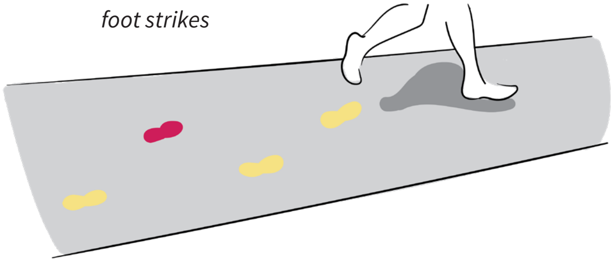
Press both buttons in less than five seconds and we will make a donation to a charity

forms of art installations can contribute to the attractiveness of the environment and stimulate people's creativity (e.g., dance an artwork). These are in line with the installations showcased in the benchmark section.

Various technological supports were envisioned to design these experiences: to log in, the use of RFID tags, QR codes or apps using geolocalization; to interact, the use of pressure sensors in LED panels or image recognition.

This strategy is particularly inclusive to various age ranges, as playful elements might appeal to a wide audience and also triggers social experiences. Existing gamified outdoor environments are usually targeting children, so there is an interest in designing interventions beyond this target group. One limitation however is that the novelty effect of some of these concepts might fade over time.

foot strikes

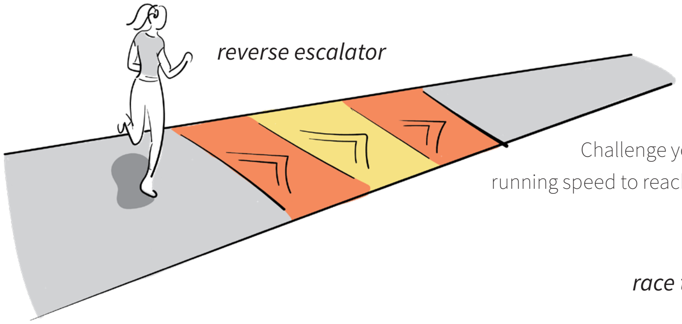


Understand and improve your running footstrike based on visual feedback

musical cadence training

Stay in time with the beat to improve your running cadence

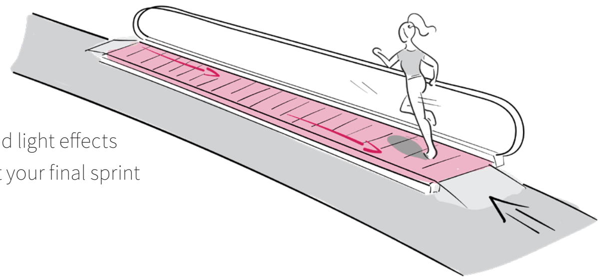
PERFORMANCE



reverse escalator

Challenge yourself and increase your running speed to reach the end of the treadmill

race to the finish line



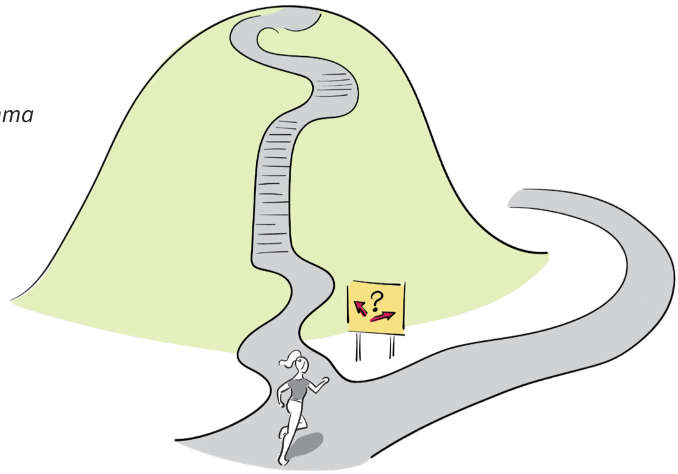
Sound and light effects will boost your final sprint

Performance / Competition

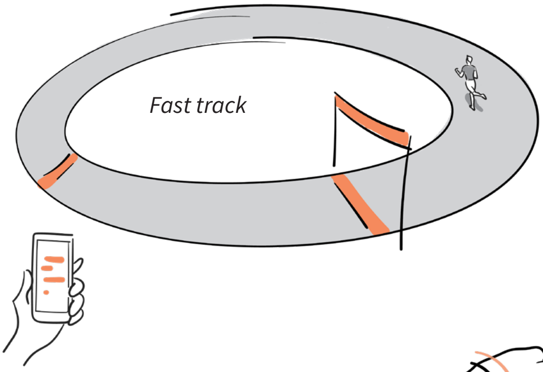
Besides leisure use, a number of sketches from our explorations used competitive or performance-related elements. These use mastery and the need for competence as a main trigger for engagement. On the technical side, the ideation focused on running training such as cadence, interval training or adequate foot strikes (e.g., musical cadence training, foot strikes or tempo indicator). Other concepts made use of competitive elements, attempting to make users train faster or harder (e.g., dilemma, race to the finish line, or fast track).

Dilemma

Do you dare to take
the hard road?

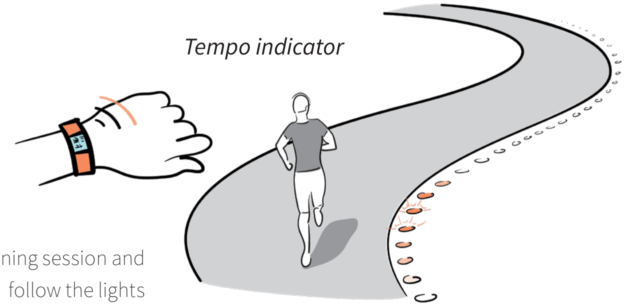


COMPETITION



Improve your own
timing each round

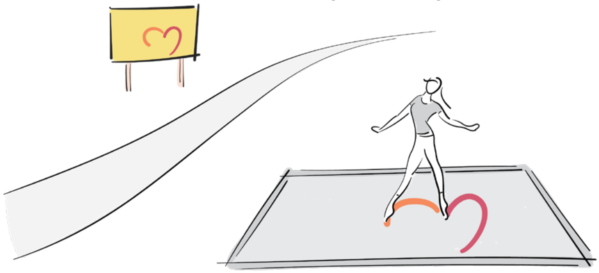
Tempo indicator



Personalize your training session and
follow the lights

These concepts sometimes require additional inputs, such as data from smartwatches or exercising apps, especially when the users wish to set personal goals or keep track of their progress over time. Exploring these options led to discussions about the benefits of personalization of these experiences. More specifically, which forms of personalization could be suitable for the design of InterActive environments where the main focus stays on a public installation that is by essence shared, and not having access to personal data about its users.

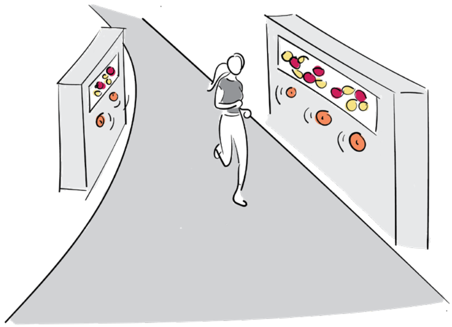
message to strangers



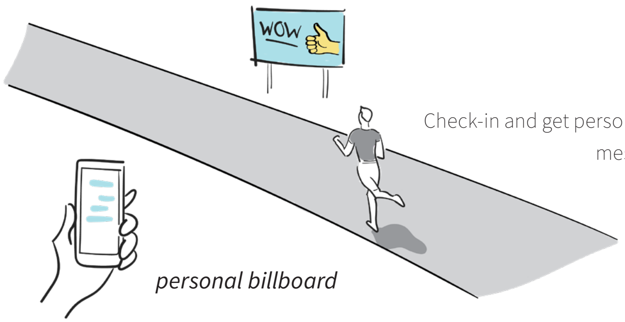
Sketch a message or emoji with your body to encourage future runners

SOCIAL SUPPORT

the clapping track



Great Job! A virtual crowd is clapping for you



Check-in and get personalized encouragement messages along your route

personal billboard

Social Support

Despite a rather individualistic view on outdoor recreational physical activity, our explorations also include sketches linked to social support. This is mostly done through a virtual representation of a supportive crowd (the clapping track), or messages from fellow exercisers (message to strangers). Some concepts adopted a tailored approach to support, by customizing supporting messages to individuals (personal billboard).

Miscellaneous

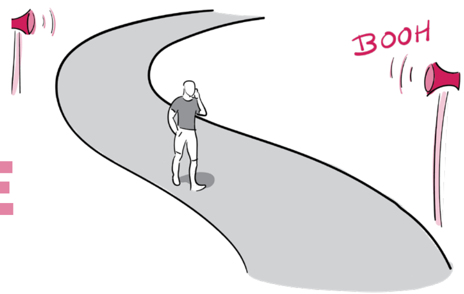
Finally, some of the sketches were harder to categorize and presented out-of-the-box ideas meant at pushing the boundaries of the design space. These covered aspects of convenience meant to overcome the obstacles related to outdoor activity: what about a human-size dryer to invite outdoor running even on rainy days? or a luminotherapy tunnel to get energized even when there is no sunlight? Starting from the reward vs. punishment idea, some concepts adopted a more provocative design perspective, by shocking (warning walk), shaming (walk of shame) or troublemaking (sinking stones). The idea of sense deprivation (e.g., walk in the dark), in opposition to the use of the different human senses as a modality for design, also falls on the provocative side.

warning walk

Warning labels depict bad healtheffects of an inactive lifestyle

walk of shame

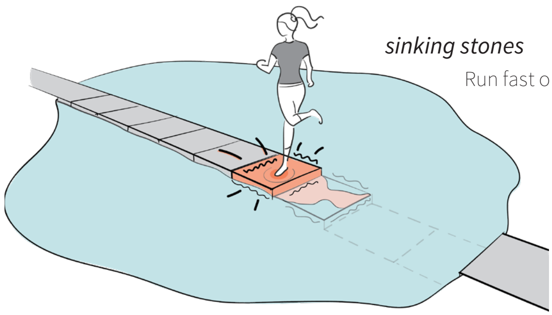
Walking too slow or stopping to answer your phone will earn you a negative cheer from your virtual audience



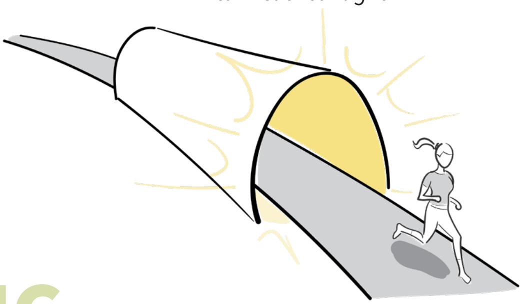
PROVOCATIVE

sinking stones

Run fast or get wet

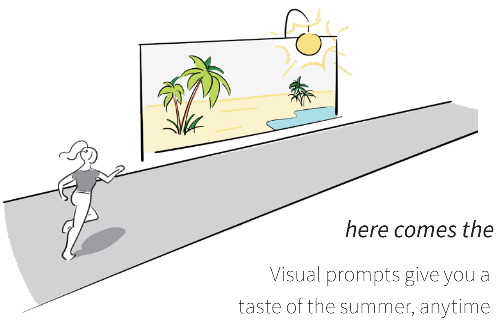


tunnel of sunlight



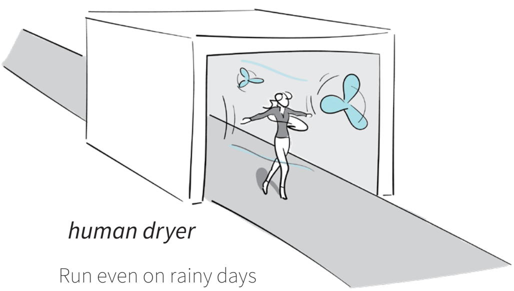
Pass through this luminotherapy tunnel to get energized

OVERCOMING OBSTACLES



here comes the sun

Visual prompts give you a taste of the summer, anytime



human dryer

Run even on rainy days

3.5 Design Cases

The broad and rather open insights gained during the concept explorations led us to identify several research questions and design opportunities. For instance, the use of sensorial modalities to "augment" the environment, the ability to personalize an experience without accessing personal data, or the use of modular gamified elements triggering discovery.

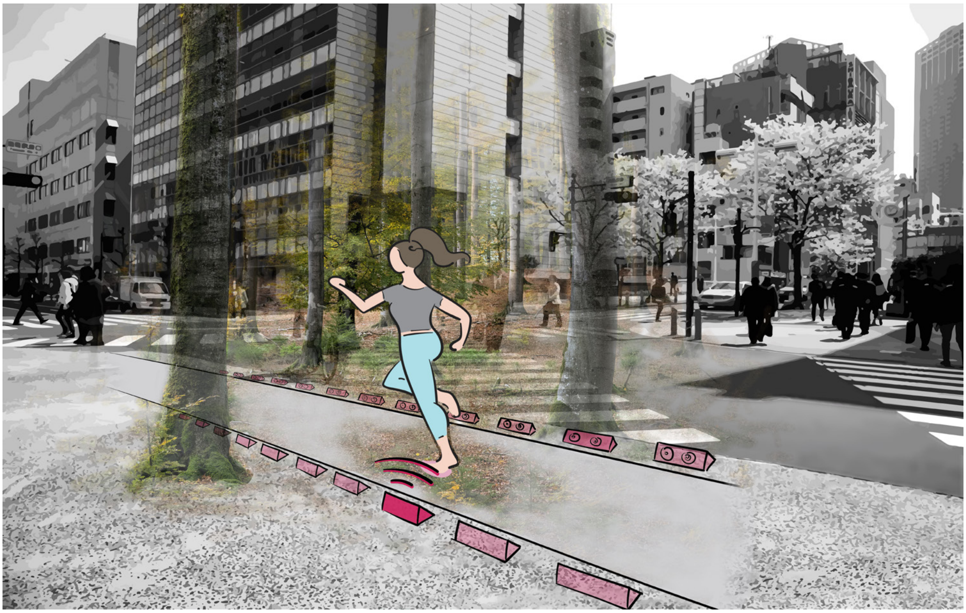
Following a Research-through-Design process [357,358], we prototyped three concepts - each representing a different design strategy - and deployed them during field tests. The design cases presented in this section are to be understood as design exemplar feeding our exploration of the design space. It is thus out of the scope of this pictorial to describe the user evaluation methodology and findings in details. We thus report on general impressions able to feed reflections around the interActive environment design space.

3.5.1 Guided by Lights: Personalized Feedback

Guided by Lights [262] is a LED path combined with a live speed indicator that supports runners or walkers to set personal goals and gain intrinsic motivation to be physically active. The design focuses on aspects that positively impact motivation and/or performance: personalization, goal setting, and feedback mechanisms. An initial evaluation of a prototype placed in three public parks, showed that participants (N=35) appreciated the personalization of the route and its goal-setting opportunities. They however found the visual light feedback hard to perceive during daytime. While embodying a form of personalization, the use of the system remained anonymous (the first part of the track measures one's speed and the light followed it subsequently), which offers advantages to onboard any user in the park without the need for an additional system.

3.5.2 DISCOV: Challenge and Exploration

Discov is a network of physical waypoints that triggers to explore its surroundings in a fun and challenging way by creating an engaging walking experience. Discovpoints attract passers-by with light feedback, who can then interact with it to get different kinds of light feedback. The Discovpoints do not form one route together, they simply show in which direction other Discovpoints can be found when users step off again. This encourages users to continue their playful and healthy discovery journey in the urban park at their own convenience. Through its engaging and explorative nature, Discov additionally increases mindfulness as it distracts people from their day-to-day worries by drawing their attention to their current surroundings. First user tests (N=15) showed that an initial interaction helps to let people know it 'does something' but keeping it vague inspires first curiosity and then satisfaction. This both lengthens and enhances the interaction. Similarly, the direction indications were clear enough to demonstrate there are more points to find, but the distance and multiple point signals were not always understood. Again, this caused some confusion that mostly added to the desire to explore and find out. A good balance between obvious interactions and hidden aspects can trigger interest and exploration, and helps to engage users over a longer time.



3.5.3 Sensation: Augmented Environment Through Sensorial Design

Sensation [264] is a sonified running track that that enriches the experience of running by providing sensations of nature through audio feedback. It detects footsteps on its surface and produces synced sounds of footsteps from a selected nature landscape (breaking branches, water puddles, leaves or snow) to augment the urban landscape. Building on the knowledge that adding natural sounds helps to improve the urban sonic environment [267] and more natural surroundings are preferred by runners [82,168,202], Sensation uses natural sounds as audio feedback to improve the sonic landscape and support feelings of relaxation and mindfulness during a run. Embedded in the physical environment, Sensation is accessible to all passers-by, and therefore more inclusive than any concept requiring a prior investment or conscious action from the user. An initial user test showed that locating the speakers close to the foot adds to the 'natural' feel, while wearing headphones were perceived as more artificial and inducing disconnection with the physical environment. Additionally, when embedded in the environment the positive effects of the added natural sounds benefit all close enough to hear. Further user explorations showed that the special experience offered by the artefact could attract people into the urban park. A side effect could also be to attract children and families in search of playful environments.

3.5.4 The Crowdsourced Marathon: Social Support

The crowdsourced marathon [43] is a futuristic marathon experience, focused on the relation between the crowd and the runners. After this exploration of cheering feedback, including a remote dimension, we reflected on how to translate the social aspects of the concept to an urban park environment.

The popularity of social platforms amongst recreational runners (e.g. Strava [302], Runkeeper [101]) indicates a need for social support about one's achievements. Transferring the cheering wave to a more casual running context, and allowing one's friends to cheer for us during a running session, might trigger a meaningful social experience. In this exploration, the combination between physical elements in the environments and a smartphone application was of special interest and provided rich opportunities for interaction.

3.6 Reflections

In this exploration we analyzed benchmarked projects, exploratory sketches and design cases, with a specific focus on interaction modalities, intervention strategies and the technological opportunities and challenges. The present work proposes an initial classification of the design space of interActive environments. It does not claim to present a comprehensive list of all possible interactions, intervention levels or technologies, but the examined examples highlight a number of interesting insights meant to inspire researchers and designers. Through our benchmark and expert interviews, we noted that examples of truly interactive urban environments are somewhat scarce.

Urban spaces and especially public parks offer a lot of low tech equipment (e.g. calisthenics equipment, cycle lanes) with installations often focused on children (e.g., playground design). This is in line with studies reviewing characteristics of urban parks associated with park use and physical activity [202,230]. High-tech interactive sport installations [5,25] appear as ephemeral initiatives, initiated by sports brands for branding purposes. They impress by their innovativeness yet seem hard to fund and maintain by public authorities. Similarly, artsy public installations triggering movement [74,75] attract a lot of attention from the public and the media thanks to their high creativity level, yet they also fail to sustain and scale up. An interesting question is: How can we translate the poetry and engagement created by these installations to a sustained use in public parks?

From the classification matrix of our exploratory sketches (Figure 3.13) and design use cases, we see opportunities to explore the richness of interaction modalities beyond the common visual light feedback. Even using LED technologies, creative freedom remains vast. Other affordable sensors offer new design opportunities: RFID tags, bluetooth beacons, pressure sensors and more. Many of the concepts we explored involved a network of modular elements wirelessly connected to each other, locally or via the cloud. This enables more integrated, holistic solutions for a harmonized experience, unconstrained by the scale of the urban public space.

The increasing amounts of both user-generated and environmental data at our disposal provide new insights into personal behavior and preference. Combined with technology, this data can also be used to tailor users' experiences, even in the urban space. Despite the variety and availability of sensors, in this exploration of the design space of interActive environments we see a limited use of the data they provide. Mainly used to trigger a direct response, usually in the form of pre-set visual or auditory feedback, user data is not further processed or utilized. Following the recent 'Data-enabled design' approach by van Kollenburg and Bogers [35], data could be used as a creative material to gain user insights trigger innovative ideas within design processes. Additionally, the opportunities this type of data use provides regarding remote alterations, updates or problem solving of the system are specifically suited for installations placed in the public outdoor space. While privacy is obviously a key concern and endeavor, especially in the public space context, user-generated data could support the design of tailored interventions which are important in the domain of behavior change.

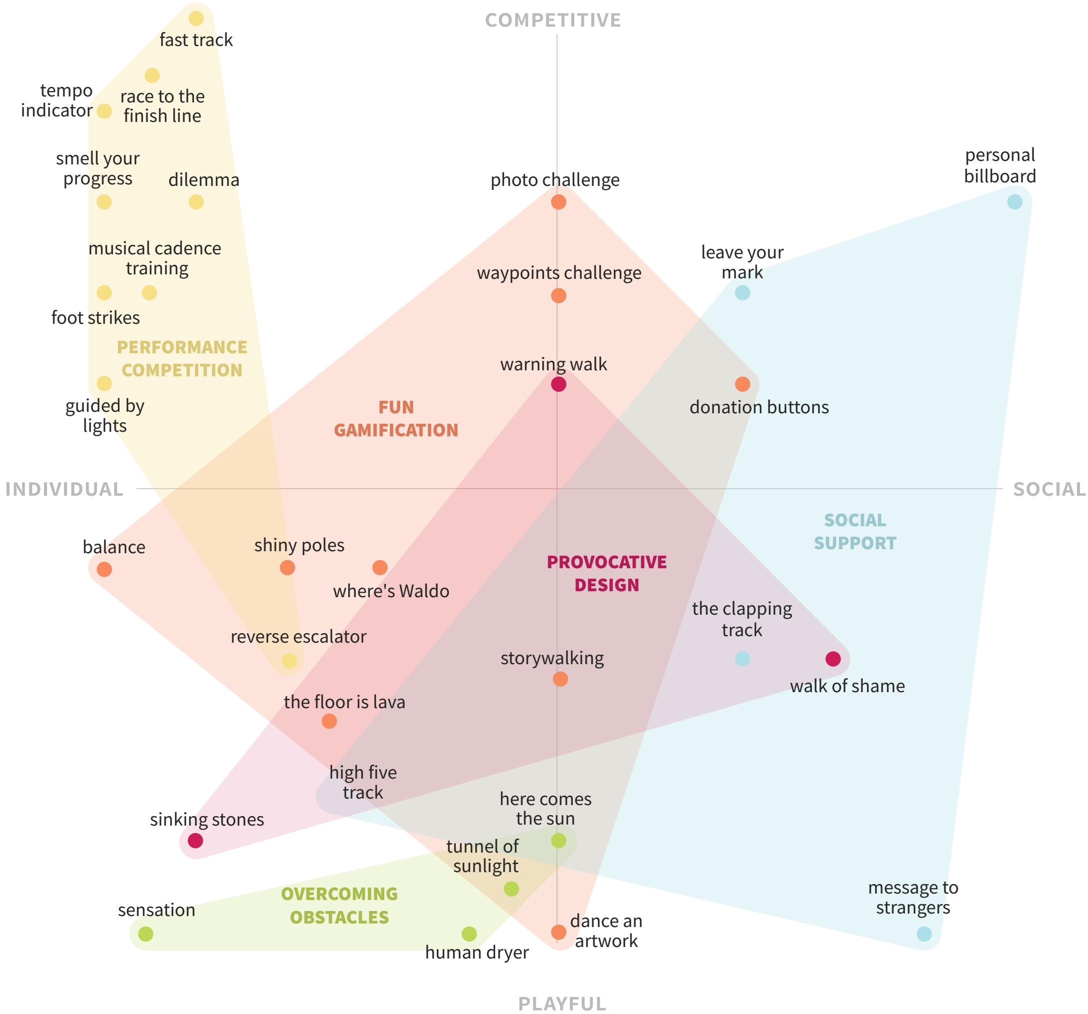


Figure 3.13: Design Explorations Classification Overview.

With their technology embedded in the physical environment, interActive environments have the potential to reach everyone in their vicinity, without any prior investment required from the user to benefit from the experience. This makes these interventions much more inclusive than many other available technologies to increase physical activity, even for the hard-to-reach group of people who are not consciously trying to change their inactive routines. Based on the limited number of more permanent installations we encountered, keeping users engaged in the long run might however prove more challenging. Future reflections could revolve around using the potential of technology to personalize these interactions [297] and the need for adjusted and more interdisciplinary approaches that will be needed to design these truly interActive environments.

3.7 Conclusion

In this pictorial, we explored the design space of interActive urban environments through a benchmark, sketches, and designed artefacts. This analysis, inspired by the authors' own experiences researching and designing interActive environments is a relevant and timely contribution to consider how technology can help understand and shape human behavior in urban space. We envision the present design space to create a base for discussing challenges and issues related to this topic and to provide inspiration for designers and practitioners.

Acknowledgements

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Guided by Lights

Stimulating Physical Activity through
an Adaptive Personal Light System

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4.1 Introduction

Physical inactivity is a major public health concern for many governments. Amongst interventions at the individual or social level, urban planners and policy makers have started reflecting on the design of active urban environments, supported by technology. To increase physical activity and social cohesion, the *Slimme Beweegroute* (Smart Exercise Route) was installed in Eckart park in Eindhoven (Netherlands) in 2017. This running and walking route resulted from co-creation sessions with the neighborhood. It consists of LED tiles on the ground, powered by solar energy. Users can choose one of four preset speeds by stepping on a colored tile. The LEDs will light up sequentially, matching the selected speed. The system aims to motivate people to keep their pace and exercise frequently.

Interviews with municipality representatives and citizens showed that the route has had technical issues from the start, which led to a bad reputation and low usage rate. The main issue identified when the route was functioning were the fixed speeds, not matching the user's desired pace. Interviewees also indicated the LEDs were hardly visible and some had trouble understanding how the route works, despite the information board. We thus researched how this route could be improved to stimulate the motivation of people to run or walk in a park, focusing on making the light system adaptive and personalized. This chapter provides insights in how an intervention in the environment can influence people's behavior and stimulate them to be more physically active.

4.2 Related Work

Urban environments have the potential to strongly contribute to physical activity through their design [275], especially with possibilities of evolving and increasingly integrated technology continuously adding new opportunities [297]. Technology also enables new and enhanced ways for tailored design and personalization, which are typically more impactful in design for motivation and sustained behavioral change than universal designs [235].

The research presented in this chapter explores the value of a more interactive and personalized running experience. There is ample research available on personalization through interactive technology in the Human Computer Interaction (HCI) community [297], that argue personalization plays an instrumental role in motivation [284]. Here, we position our work in research that relates specifically to physical activity and running. Looking into enhancing advanced amateur runner's experience, Knaving et al. (2015) proposed design guidelines for future runner support technology. These include the importance of allowing runners to define personal and social goals to strengthen internal motivation. Regarding feedback, they urge designers to use non-intrusive interfaces that minimize distraction during a run [157].

Enhancing interest for an activity, goal-setting can increase motivation, especially when the motivation is intrinsic [284]. The strategy of goal setting was used by another interactive running route, located in Oosterpark, Amsterdam. Bluetooth beacons with a connected app tracked a runner's speed and position. Messages via the app suggested exercises, goals, to the users [76]. These goals, however, are set by a system, while autonomously set goals result in better performance [284].

Reflection on goals creates more awareness, helping to set the right goals and improve skills and motivation [179]. Additionally, allowing goal progress monitoring promotes behavior change [130]. *GoalLine* and *GoalPost* are research probes used to investigate physical activity motivation using goal-setting, rewards, self-monitoring, and sharing [219]. Using primary and secondary goal-setting resulted in increased motivation of participants. However, the reward system and sharing feature relied on extrinsic motivation and did not have the desired effect.

To measure achievements and recognize reached goals, system feedback is important. During a run, haptic and visual feedback by light could motivate people to persist [351]. The interaction can become more effective when varied feedback is used [17]. Feedback systems for runners should provide simple visual output, being more effective than auditory feedback and requiring little cognitive effort during a run [351]. Providing visual feedback for self-monitoring through an app is effective for increasing physical activity [220]. However, while smartwatches and smartphones can present large amounts of data, these interfaces are not optimal for in-run feedback [66]. Exploring other ways of presenting data, they developed a shoe that gives feedback on running pace through light signals. Similarly, the interactive shoe *Pediluma* lights up when walking as immediate positive feedback [182]. It had a positive effect on the step count, yet users felt uncomfortable with the light at night and preferred a goal-reward system. For our design, we build on the successes and recommendations of this previous work to create a lighted path that motivates people to be more active.

4.3 The Design

To research the influence of personalization of the designed route, we created a prototype of the new light route, including an improved and brighter light system and a shorter distance between the lights. The system is now tailored to each user; aware of his/her pace and lighting up accordingly. Additionally, this lets users track their progress and set goals.

The prototype-setup is 55 meters long. The user's speed is measured within the first five meters. After another five meters, a LED matrix displays their speed, allowing personal goal setting and progress tracking. The display turns off when the pace reaches the first light. From here, five poles with LEDs are placed every ten meters. These lights guide the journey of the user and provide feedback every ten meters. The lights turn on when the user should be next to it, based on their speed in the measuring section. The LEDs are red, as this color showed to be most visible in contrast to the green park and was seen the brightest in sunlight.

Figure 4.1: System Setup. ▶

4.4 Method

As inspiration for this research we used the Experiential Design Landscapes approach, where design propositions are placed in people's everyday lives. Using sensors and smart technology, their experiences and behaviors are captured and analyzed, identifying patterns and creating new design opportunities [246].

Pilot Study

Eighteen interviews were conducted with park visitors, to understand their mindset regarding exercising and running in this environment. Questions about the current light route were included to investigate people's pre-existing knowledge about the route and if they used it.

Research Setup

After the pilot interviews, two observation studies of 3.5 hours each took place in Eckart Park and Stadswandelpark. A third experiment took place on the Eindhoven University campus. The goal of the first observation studies was to observe if park visitors would spontaneously use the system and how they interact with it. Researchers observed from a distance without interacting with participants. Users that adapted their pace (N=2) also filled out subscales of the User Experience Questionnaire (UEQ) [256] related to attractiveness, perspicuity, stimulation and novelty of the system.

The third experiment was focused on motivation for physical activity and the design's appearance. Twelve participants, all students (18-25 years old) and unfamiliar with the smart exercise route, were given information on the original route and the design before filling in part of the Physical Activity and Leisure Motivation Scale (PALMS) questionnaire to measure their motivation for physical activity [354]. Only the physical and individual subscales were used. Next, participants were asked to use the course at their preferred pace. Observations were made on pace and attention paid to the display and lights. After the test, participants filled out the UEQ subscales. Open questions were added to better understand participants' replies.

4.5 Results

During the first observations 23 people passed the testing area. Eight of them (34%) interacted with the adaptive light route and only two (9%) adapted their pace to the route. Mostly young people (up to ca. 20 years old) interacted with the route. Observation showed that the novelty of the setup at the second location did not significantly influence the results.

The UEQ shows that although the design is not perceived as very novel or innovative (Novelty subscale: M= 0.6; SD= 1.4), respondents found it attractive (M= 1.1; SD= 1.2) and somewhat stimulating (M= 0.9; SD= 1.3). The design scores highest on perspicuity (M= 1.4; SD= 1.6), meaning it is understandable and easy to use.

Regarding motivation, responses to the open questions (N=12) can be sorted into three categories. Two participants did not find the route motivating at all; *"I'm not a running fan, design could be more*

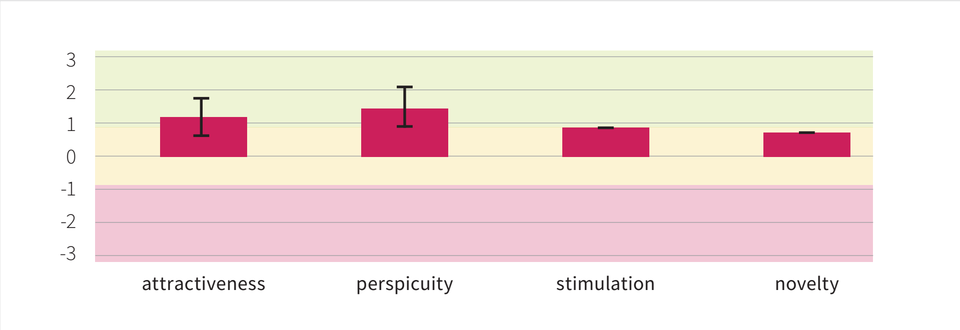

Figure 4.2: UEQ Scales (Mean and S.D.).

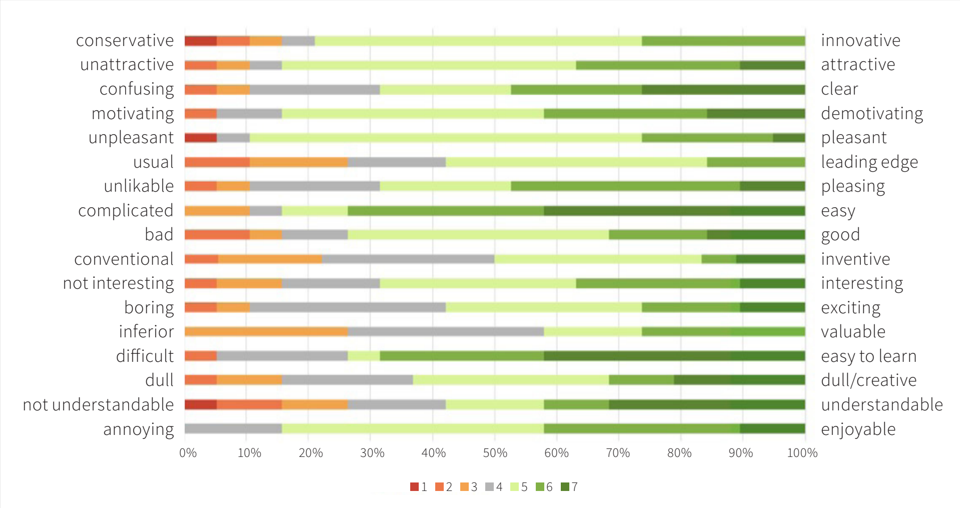

Figure 4.3: UEQ Answer distribution per item.

innovative or fun." (participant 1). Five participants found it potentially motivating but were not sure based on this test, *"I can imagine the whole route can be motivating. The user test was such a small part that I find it hard to say anything about this."* (participant 12). Five others found the route motivating and positively experienced the personalization of speed *"nice to complete a milestone with each light"* (participant 2).

People found the best time to encounter the route would be when walking, running or playing sports, especially in the evening. The most mentioned motivations to use the system were to improve oneself and using the lights for guidance during so there's no need to think about directions. Main points of feedback were the length of the prototype route and the visibility of the lights. Suggestions were given to provide more information at the start of the route, to make the design more remarkable and to further personalize the route with colors; people indicated that controlling the light color or pattern would make them feel more connected to the system.

4.6 Discussion

Motivating people to become more active is a complex challenge, because motivational factors differ per person. Other influencing factors are uncontrollable, such as the weather. For our design, we focus on personalization, goal-setting, visibility and understandability.

Personalization

In line with the literature review, the main reason for the increased motivation was the personalization of the route. However, the 55m of prototype setup was not long enough for all participants to form a clear opinion about the effect of the system on a longer circuit. Observations also showed that five meters are not enough to measure the user's speed. People did not have a constant pace, resulting in many participants not finishing alongside the light indication.

Goal-setting

The related work showed that goal setting and appealing to intrinsic motivation, can increase motivation to be active, while not being forced to do so. The new system depends on the user’s memory and willingness to improve their speed. Yet, some people indicated they may still need an extra push to exercise.

Because of the small sample size, generalization of this research is less reliable. While being the target users, people living near Eckart Park were already familiar with the original light route. This possibly influenced their opinion or interaction with the design during the first experiment. To get a more objective view on the project, another observation was done at the Stadswandelpark, where the visitors and participants largely represented the target users. All participants in the experiment on university campus were 18-25 years old. Even though these ages are part of the target group, this group does not fully represent the residents of the neighborhood.

Because of ethical regulations, a sign informed people that anonymous data would be collected if they proceeded along the route. This clearly influenced the results, as people intentionally avoided the area and were less inclined to interact with the design. While we conclude that personalization creates more motivation for people to run/walk, this does not yet show a direct relation between increased motivation and actually using the route.

Visibility

The design was enhanced to improve visibility of the LEDs and, based on conclusions from related work, also give them more meaning for the user. Observations showed that the new system was noticed more in the park setting and drew the attention of people passing-by. However, they were not always visible in bright sunlight, making the user test inconclusive for some participants.

Understandability

Despite a positive score for the system’s understandability on the UEQ, it is not clear from these results to what extent this only lowers the threshold for using the design or actually affects the motivation for physical activity.

4.7 Conclusion

To increase people's motivation to run or walk more through design, multiple aspects need to be taken into consideration. The personalization of the route; adjusting to the user's speed, is experienced as more pleasant and creates a connection with the design. It also provides the opportunity to set and check personal goals. Additionally, the Guided by Lights design is more visible than the original system and efforts have been made to make it more self-explanatory and understandable. When designing for behavior change, this combination of personalization, goal-setting, visibility, and understandability is essential for any similar system to boost motivation and physical activity.

4.8 Future Work

To improve the personalized running route concept, further research needs to show the effects of a longer route and the impact of repeated speed measurements along the track. A next iteration of the design should be longer to test the effect more thoroughly. A longer run-up and speed measuring in multiple places can help staying connected to the user's pace and allow for personal training variations. Brighter lights or color patterns can increase visibility. Next to that, patterns or a connected app could enable further personalization or a playful element in the route, motivating people to use the lights in a new way. Additional studies can also help to determine in which stage of a run this design is most effective. These iterations would create a better connection to the user, providing new and improved ways to motivate people to walk or run.

Sensation

Sonifying the Urban Running Experience

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5.1 Introduction

Physical inactivity and the resulting health concerns are an important societal challenge in modern western societies [33,159,334]. For people, physical activity is influenced by a combination of individual, social and environmental factors, and the design of urban environments can therefore be an effective tool to subconsciously nudge people into moving [275]. The design of healthy urban environments has been prioritized by the European Commission, due to estimations of a high increase in urban living [98]. This includes the improvement of general health, by increasing public vitality [33].

Physical activity is perceived as more enjoyable in a natural environment [136], yet citizens who live in high density urban environments often do not have easy access to this. Public parks thus have an important role in facilitating physical activity [26]. They include children playgrounds, sport or exercise facilities and running or walking routes. Many parks are designed to provide social interaction, nature and recreation [193], but especially the nature element is hard to recreate in a completely man-made environment.

In order to help motivate citizens to increase physical activity on a daily basis, we created *Sensation*, an interactive running track that aims to strengthen the positive effects of running in nature. Although focusing on runners, the design also accommodates walking at a slower pace. The design aims to increase the joy and relaxation factors of a run, by adapting to the existing workout, and providing different sounds of nature. Through *Sensation*, we contribute to research on the effects of sonification as an interaction modality in the context of running. We also focus on how public infrastructure and human-environment interactions can nudge citizens into being more physically active. We discuss the implications of designing for public spaces as compared to smartphone applications.

5.2 Related Work

It is well known that a more active lifestyle contributes significantly to overall health, but many people still struggle to embed enough physical activity into their everyday routine. This makes promoting and supporting an active lifestyle a timely and popular research topic, with extensive work already done in this area. In our research, we focus on running as an example of a popular form of physical activity that takes place in the urban environment.

A wide variety of technologies has been developed to aid and motivate people to keep up the pace and reach activity goals, and runners have easy access to a large variety of available mobile applications, smart-watches, wearable devices or other activity trackers, targeting runners with a wide range of goals and experience levels [142]. While apps guide their activities by providing navigation through or an augmented layer over the physical environment you are in (e.g. *Runkeeper* [101], *Strava* [302], *Pokémon GO* [228] or *Zombies, Run!* [295]), smartwatches, other wearable trackers and displays [66,200] provide immediate personalized feedback during the run, allowing for instant adjustments. Most of these technologies no longer solely focus on performance [215] and often include a form of gamification or a platform to share data or experiences. But with their objective performance measurements, training schedules, challenges and (positive) peer pressure, they still push users towards a performance-based mindset regarding the user's running routine.

Even though this is a positive trend that supports increased physical activity, it does leave another important part of the running experience overlooked; the mindful, positive feeling people get during and after their run [87]. Applications focusing on this aspect tend to target walkers rather than runners, e.g. *Ambient Walk* [56], and varying mindfulness apps offering walking meditation or mindful walks, such as *Calm* [46], *Headspace* [133], *Stop, Breathe & Think* [299]. This calm feeling and sense of self is strongest in a green or natural environment, where people enjoy running the most [82,136].

For many city-dwellers, running in a true natural environment is not achievable on a regular basis. They often spend large parts of their runs in public parks, the closest approximation of that green environment available to them. Even when well-designed visually, these parks still lie in dense urban areas, with city noises detracting strongly from this experience [341]. This sonic environment can be improved through the soundscape approach, adding (human-preferred) sounds rather than diminishing unwanted sounds [267].

Urban environments have the potential to strongly contribute to physical activity through their design [275], especially with possibilities of evolving and increasingly integrated technology continuously adding new opportunities [6,297]. Technology also enables new and enhanced ways for tailored design and personalization, which are typically more impactful in design for motivation and sustained behavioral change than universal designs [235].

The implementation interactive technology in everyday urban environments to support physical activity can be seen in projects like the *Piano Stairs* [311], *Musical Swings* [74] or *NIKE's Unlimited Stadium* [25].

These installations, however, all have the temporary character of a pop-up installation. They invite to be active by drawing attention and engagement of passers-by, but only for a limited time. Their popularity shows the positive impact such environments can have on the physical activity of people, but give no clarity about the long term effects. More permanent installations such as *The Pearl Divers* [75], *Run!* [204], or *Slimme Beweegroute* [76,262] are more rare but indicate a continued use, even in the long term. Through this research we explore the potential of such an interactive environment to create a more enjoyable running experience by bringing a sensation of nature to an urban park.

5.3 Sensation

5.3.1 Design Concept

Sensation is a physical interactive path that lets urban runners experience a more natural environment through audible feedback while running. The path detects footsteps on its surface, matching them with sounds of footsteps in various nature settings (footsteps on leaves, snow, branches or a puddle of water) (Figure 5.1).

The volume of the audio feedback depends on the stepping force of the runner; a hard step results in a higher volume, and a soft step will be harder to hear. Furthermore the program is equipped with a randomizer so that a runner will never recognize a pattern in the sound feedback they hear. The speakers are located on both sides of the path in order to shift the origin and balance of the sound towards the left or right foot, depending on where the impact is made.

To personalize the experience, runners can select their preferred sound feedback by stepping on one of four buttons at the beginning of the track. Each button shows an icon representing the environment of the related feedback sound. Next to personalization, these options also aim to keep the runner curious and invite them to return and try a different sound.

By adding these synced natural sounds to the urban sonic environment, *Sensation* aims to enhance the feeling of running in a natural environment and therefore help runners to experience more relaxation and enjoyment during their run. This is especially valuable for inhabitants of urban areas who cannot easily include genuine nature in their running route. Since this is conceived as an important factor of running enjoyment, *Sensation* increases awareness of the importance and influence of nature and motivates runners by providing a more enjoyable running experience. Embedded in the physical environment, *Sensation* is accessible to all passers-by, and therefore more inclusive than any concept requiring a prior investment or conscious action from the user.

5.3.2 Prototype

To test the concept of *Sensation*, we created a physical prototype consisting of sensor pads, placed in pairs under rubber tiles (Figure 5.2). Each pair of sensors is placed next to each other to distinguish between a left and right foot strike and linked to two corresponding speakers on each side of the track. The prototype is battery powered. The track is best placed on a path with a hard surface, such as asphalt or concrete, and at least about 2.5 meters wide to ensure enough space for other passers-by.

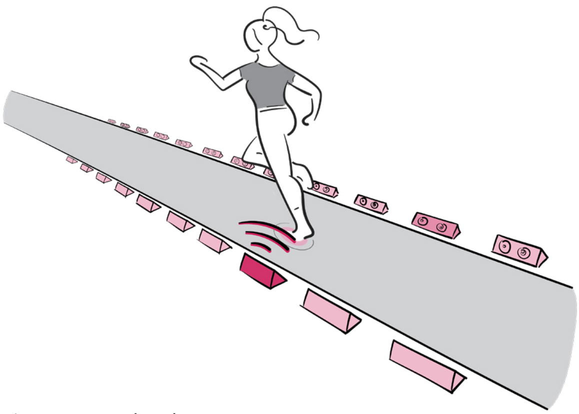
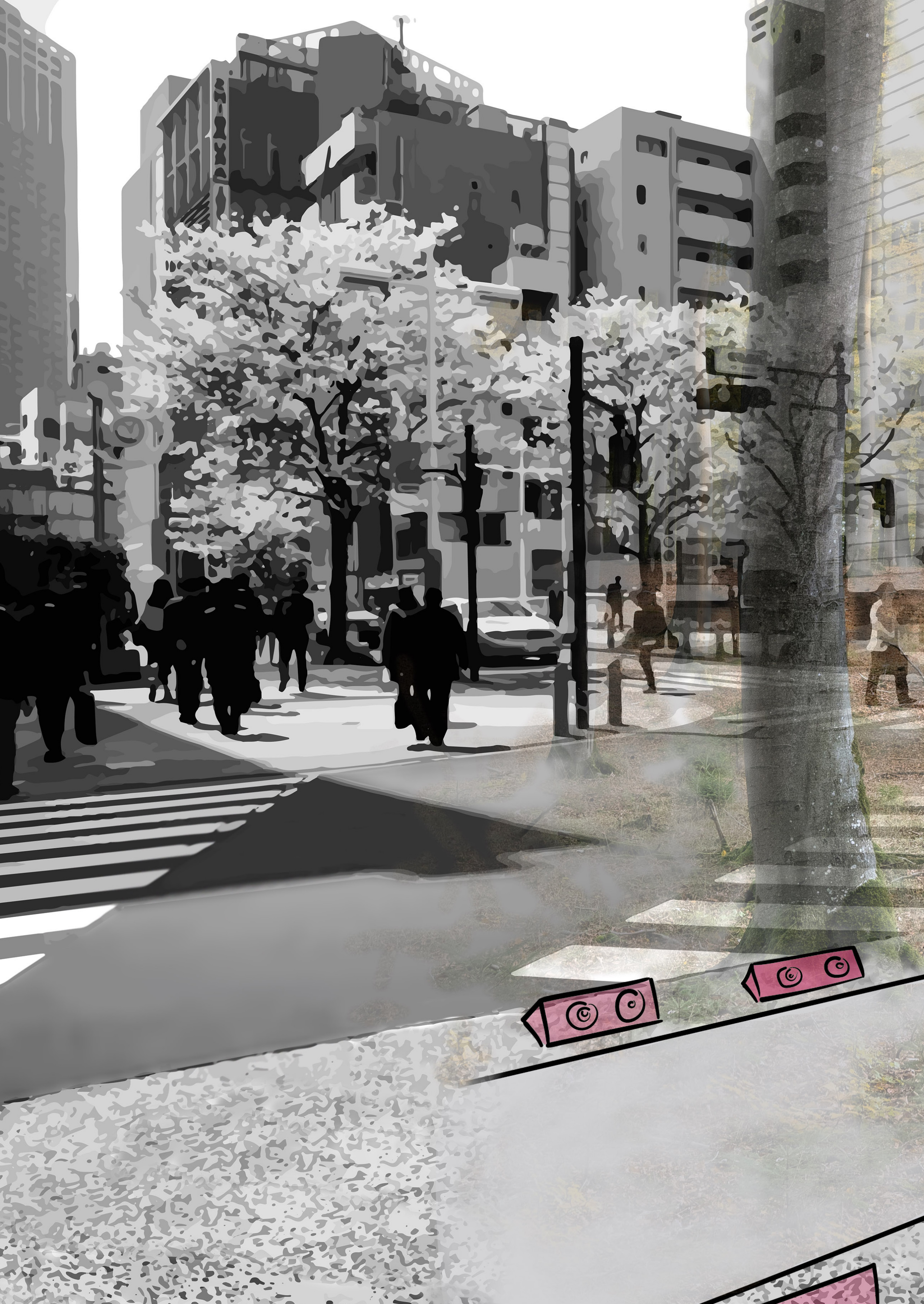


Figure 5.1: Sensation concept sketch.



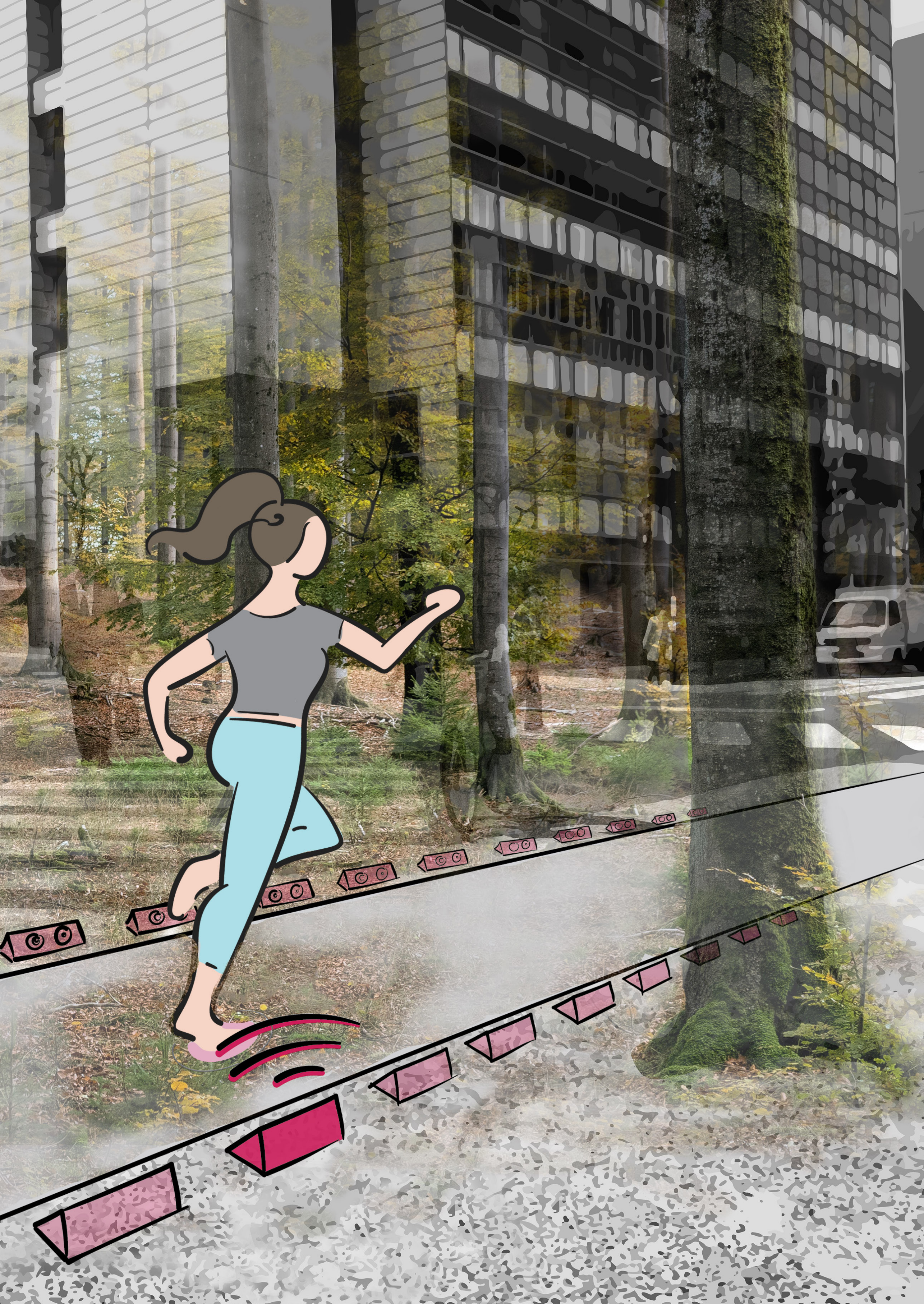


Figure 5.2: Sensation prototype.

5.4 Design Process

5.4.1 First Explorations

In this project, we followed a research-through-design approach. First, we gained insights into the practice and experience of running through seven interviews with experienced runners (6 men, 1 woman, age range age 41 to 57 years old), one of which was done while running. When asked about their motivation to go running, participants often mentioned relaxation (P1, P4, P5, P6, P7) and enjoying their surroundings (P1, P2, P3, P4, P5, P6). The relaxation mostly arose from "being able to clear your head" (P1, P3) and being in a natural or calm environment (P1, P3, P4). Considering running environments, we noted a clear preference for running in nature, for which variation in sight and surface were given as most important motivation next to relaxation. This environment helps to 'clear the head' by providing variegated and pleasant visual and audible elements, helping runners to "see the little things" (P2, P4). This distracted from other thoughts and helped to stay present in the 'now'. Other frequent reasons for running were to have a feeling of living healthy.

Two of the authors also adopted a first-person perspective. By going for runs in different environments (urban streets and parks, forest and open field), we experienced the running sensations and the impact of the environment on the run. We also used previously available literature and datasets [260,304] to research what routes are popular in a specific location and how these differ from the unpopular ones, comparing these to our own observations.

Based on these explorations, we focused on creating a more stimulating, engaging or enjoyable running environment in the urban area. Since the design goal is to enhance a feeling of relaxation and mindfulness, it is also important it provides little distraction to the runner. The design should be seamlessly incorporated in existing running routes. As interactions based on light would not be ideal for routes that are predominantly used during daytime, we decided to research the use of sound as an interaction modality to bring that peaceful, enjoyable sensation of running in a natural environment to the urban area, making it accessible for all runners there.

5.4.2 Pilot Study

A pilot test was conducted with three participants (with running experiences ranging from moderately to very experienced) to improve the concept of *Sensation* (Figure 5.3, 5.4). The test location was a park in an urban area (Genneper Parken, Eindhoven, NL). This section of the park has a rather natural look but is still located close to residential areas with several main roads nearby. We used the Wizard of Oz technique to test a long track without needing a large prototype. Participants used headphones to receive the audio feedback, based here on manual input. Participants were asked to cross the indicated track four times, selecting a different type of sound feedback each time by stepping on the sound selection buttons. After the physical test participants were asked about how the audio feedback influenced their running experience, through a short interview and a questionnaire.

The nature sounds were experienced positive but felt artificial because the sound seemingly came from the sides (through the headphones). This feeling of artifice was partly why all participants were not fully satisfied with the experience. Related to this, wearing earbuds created an intuitive

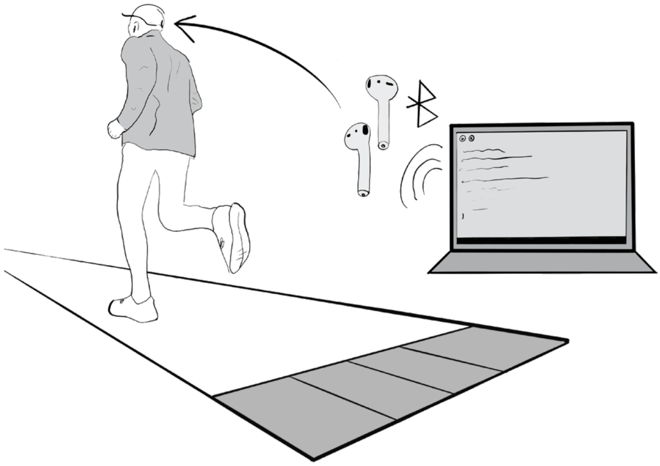


Figure 5.3: Sketch of pilot test setup.

disconnection with the physical surroundings. Locating the source of the audio closer to the stepping foot and embedding the technology in the environment will create more realistic audio feedback and increase the sense of connection to the environment. Other than this, the users liked the option to select a preferred sound but did suggest a larger variation of sound fragments per category.

5.4.3 Future Work

Future work will include several user studies to explore and confirm the most relevant design aspects; building a longer test track to better study the effect of the targeted audio feedback on the running experience and explore additions or alterations to the used sounds. Testing in an outdoor urban environment also allows to research use by non-runners. Next, determining the best track length and building a more durable prototype for a long-term test, to see how use will develop over time. In addition to qualitative data, we will also collect quantitative data during this study by counting people on the designated route before and during the test period. Since *Sensation* detects footsteps, it can also count the number of people using it. This way we can determine both if *Sensation* attracts people to its location and how many of the passers-by will use it.

5.5 Discussion and Conclusion

We designed *Sensation*, an interactive path that lets runners in an urban environment experience more natural surroundings to increase their mental relaxation and overall run enjoyment. By doing this, we can research the effect of using sonification through a physical, environmentally embedded design on the running experience. With our design we aim to encourage longer or more frequent runs, and so helping people to embed enough physical activity into their daily lives. Through this design research process we explored the potential of creating a more attractive urban running

Figure 5.4: Pilot test setup.

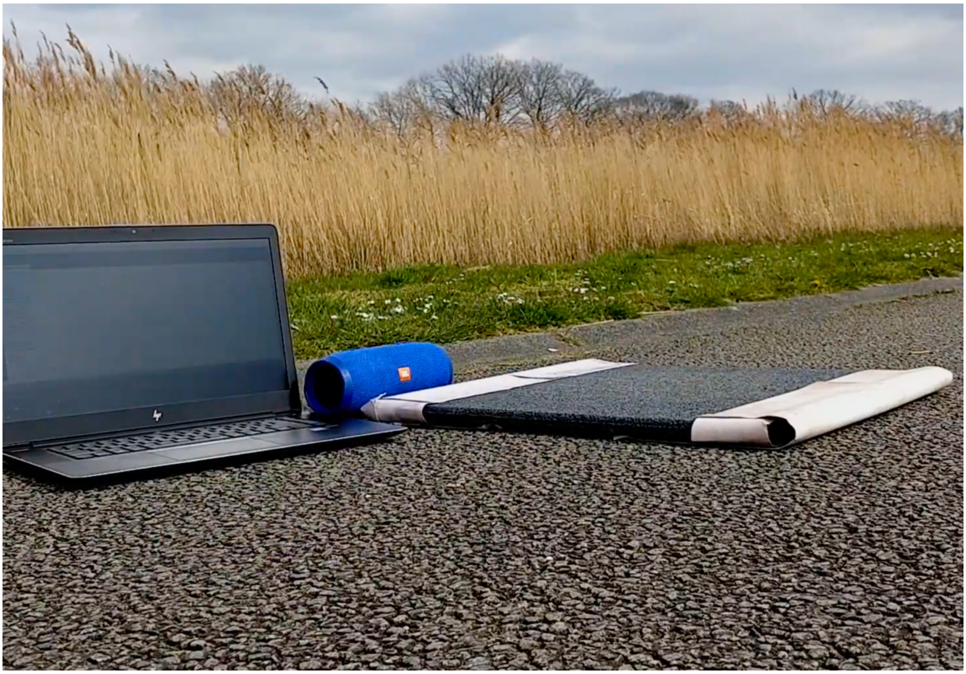


Figure 5.5: Early prototype.

Figure 5.6: Early prototype test.

environment. Instead of focusing on goals and performance, we used natural sounds as audio feedback to improve the sonic landscape and support feelings of relaxation and mindfulness during a run.

With a wide variety of apps and technologies to support physical activity and running already on the market [142,200], we address several less explored angles in this field. Where most of the existing running technologies focus on increasing performance and reaching goals [200,215], *Sensation* aims to motivate by providing a better running experience. Instead of performance, our focus lies on the mindful and relaxing experience people appreciate during a run. Adding natural sounds helps to improve the urban sonic environment [267] and contributes to the experience of more natural surroundings that are preferred by runners [82]. Using natural sounds as audio feedback, *Sensation* provides no visual distractions and is more likely to blend naturally with the perceived environment of the runner.

Although building a physical installation will require an investment from the government or community and rather low-maintenance technology, there are considerable advantages to this approach. Contrary to most other popular technologies, these interventions require no prior investment from the user such as buying fitness trackers or downloading programs. Embedding the technology in the physical environment ensures accessibility to all, making *Sensation* much more inclusive than many of the available technologies. From a public health perspective, this is an important argument, since these interactive environments even have the potential to also engage the hard-to-reach group of people who don't move enough but are not consciously trying to improve. Additionally, the natural sounds produced by *Sensation* may even improve the sonic environment of others close by.

While initially intended for runners, once installed in a public park *Sensation* is likely to also be used by walkers or (playing) children. We expect that for the walkers, the relaxing sensation of a more natural environment will add to their experience in a similar way as it does for runners. Children may additionally use the audio feedback in their play. Both of these uses would have to be confirmed in a future study but may lead to *Sensation* reaching an even larger audience. Since the sensors and speakers are located in each tile, multiple people can use the track at the same time. However, measures may be necessary to prevent (motor)bikes coming on the track.

Examples of truly interactive urban environments are somewhat scarce. Urban spaces and especially public parks offer a lot of non-technological equipment (e.g., calisthenics equipment, cycle lanes) with installations often focused on children (e.g., playground design). But with their prospective audience and influence, Human-Environment interactions have great potential as a concept to encourage physical activity and a healthy lifestyle. Including such technologies in the design of urban spaces can help to reach this goal, with the collected anonymous data used both to gain user insights and as a source for further personalized interactions.

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DISCOV

Stimulating Physical Activity through an Explorative Interactive Walking Experience

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6.1 Introduction

Physical inactivity and resulting health concerns are an important societal challenge in modern western societies [33,159,334]. Physical activity is influenced by a combination of individual, social and environmental factors [30,122,134]. The design of 'activating' urban environments can be a powerful tool to nudge people into moving [167,275], contributing to improved general health by increasing public vitality [33]. Increasingly integrated in the environment [306], technology allows for new interactions and increased personalization of those 'smart' environments, expanding their potential to trigger, enable and motivate users to change their routines [28].

Aware of the consequences of their inactive lifestyles, many people nevertheless struggle to integrate enough physical activity into their busy lives [136], perceiving it as yet another task added to their to-do list. Smart interventions that relate to existing active routines, such as (lunch)walks or bike rides, can help increase activity levels. Additionally, emphasizing the relaxing and enjoyable aspects of an activity can help relieve stress instead of increasing it [136].

To help citizens increase their physical activity, we designed Discov, a network of physical waypoints aimed to create an engaging walking experience. Placed in a public park, the design triggers people to explore their surroundings in a playful, curiosity-driven way, encouraging them to extend their walk and drawing attention to their current environment. Through Discov, we contribute to design research supporting public health through the design of accessible infrastructure and human-environment interactions nudging people into being more physically active. Adopting a Research-through-Design approach [357,358], we gained insight throughout the iterative making process, including several tests in the field with prototypes from different fidelity levels. We explored how interactive design installations can stimulate walking by creating a more engaging, fun, and social experience. We provide inspiration for design researchers who aim to impact society by encouraging a healthy lifestyle through design and technology.

6.2 Related Work

While research shows that an active lifestyle contributes significantly to overall health [159,238], many people still struggle to embed enough physical activity into their everyday routine [159]. Promoting and supporting active lifestyles is a timely endeavor. We build on the knowledge that the design of places can strongly influence behavior [327], either by offering limited options, or by nonintrusively guiding behavior, known as *nudging* [104,310]. Within the design community, we see opportunities in the field of active environment design [90,166], and in the ongoing shift towards Human-Environment Interaction [297,306], where technology is increasingly integrated in the environment. It is thus both more omnipresent yet often less noticeable, making it suitable for technology-mediated nudging [50].

This research focuses on these human-environment interactions and the potential of 'interActive environments'; in which embedded technology aims to trigger physical activity [266]. Three main elements at the core of the 'interActive environment' concept make it powerful: the influential power of the environment, tailored and adaptable interactions enabled by smart technologies, and the inclusivity that inherently comes from embedding technology in the physical environment, making it accessible to all who are present without requiring any prior investment from the user [266].

Regarding examples of such environments (e.g. Piano Stairs [311], Pearl Divers [75], Musical Swings [74]), we see that many of them neither aim for, nor establish, long-term behavior change, despite their initial appeal [266]. To support increased physical activity for a broader public, attention should be paid to people's common, everyday activities [136]. Since lack of time is a main barrier for people to forgo physical activity [145,307], interventions should be efficiently embedded into users' schedules [136]. Some of these installations indeed tie in with pre-existing activities, such as walking (e.g. Urbanimals [176], Guided by Lights [262]), running (e.g. Sensation [264], Run! [204]) or even working (e.g. the Hub [78]). Although these designs lengthen or intensify physical activity in the moment, increasing the frequency of physical activity or attracting audiences who are less prone to engage in physical activity remains a challenge.

According to Fogg's Behavior Model, three principal factors must be present for behavior change to occur: people must be *motivated*, *able* and *triggered* to perform the behavior [103]. By tying in with people's schedules and pre-existing activity routines, the 'ability' of target users to undergo behavior change is optimized. Interventions to promote physical activity should address cognitive-behavioral principles of behavior change [30], which include intrinsic motivation and dispositional mindfulness [115]. In green environments, mindfulness –a practice to decrease stress and boost positive feelings– can increase positive effects of experiencing nature [47] and outdoor exercise, which in turn can increase motivation for repetition [136].

Intrinsic motivation can be improved by triggering curiosity, providing autonomy and personalization [28,103,284]. Being a driving factor of human behavior, curiosity can be a strong instrument in achieving behavior change through interactive design. Tii Tieben, Bekker & Schouten (2011) describe a circular process of curiosity, entailing four actions: *encounter*, *explore*, *discover* and *adjust* [314]. When designing for interest, high novelty can evoke positive emotions, provided that users expect they can manage it [353]. This requires a balance between known and new, clarity and uncertainty.

Through this research, we explore the potential of an interActive environment that ties into existing activity routines, increasing activity duration and frequency by building motivation and mindfulness and creating a more engaging experience.

6.3 Design Process

6.3.1 Defining the Context

Based on a benchmark of interactive public installations and multiple sketching explorations [266], several focus points were defined. We aimed to design an interactive installation in the public outdoor space that can hook on to existing activities and uses curiosity as a trigger. The pre-established routine inserted our design into is walking, a common, low-threshold and multifunctional activity that brings people to public outdoor spaces. The study was approved by the university's ethical board.

6.3.2 First Explorations

A short survey (N=36) was conducted to learn more about users' behavior and motivation. *Getting fresh air* (n=32), *being healthy* (n=27) and *spending time with other people* (n=16) were given as main motivations to take a walk. *Bad weather* (n=29), *busy schedules* (n=21) and *lack of motivation* (n=17) were the most common reasons not to go. Notably, 27 respondents desired to walk more often. This group is likely susceptible to a persuasive design, either to extend an existing walk or plan an extra one.

Building on the concept of curiosity [314], our design should therefore draw attention and engage, creating an interesting and fun walking experience. Since it focuses on nudging people to extend their walk, users should be free to determine their own pace. Additionally, it should fit into busy and varying daily schedules, leaving users free to stay within the amount of time they have available. We explored the solution space through sketching (Figure 6.1).

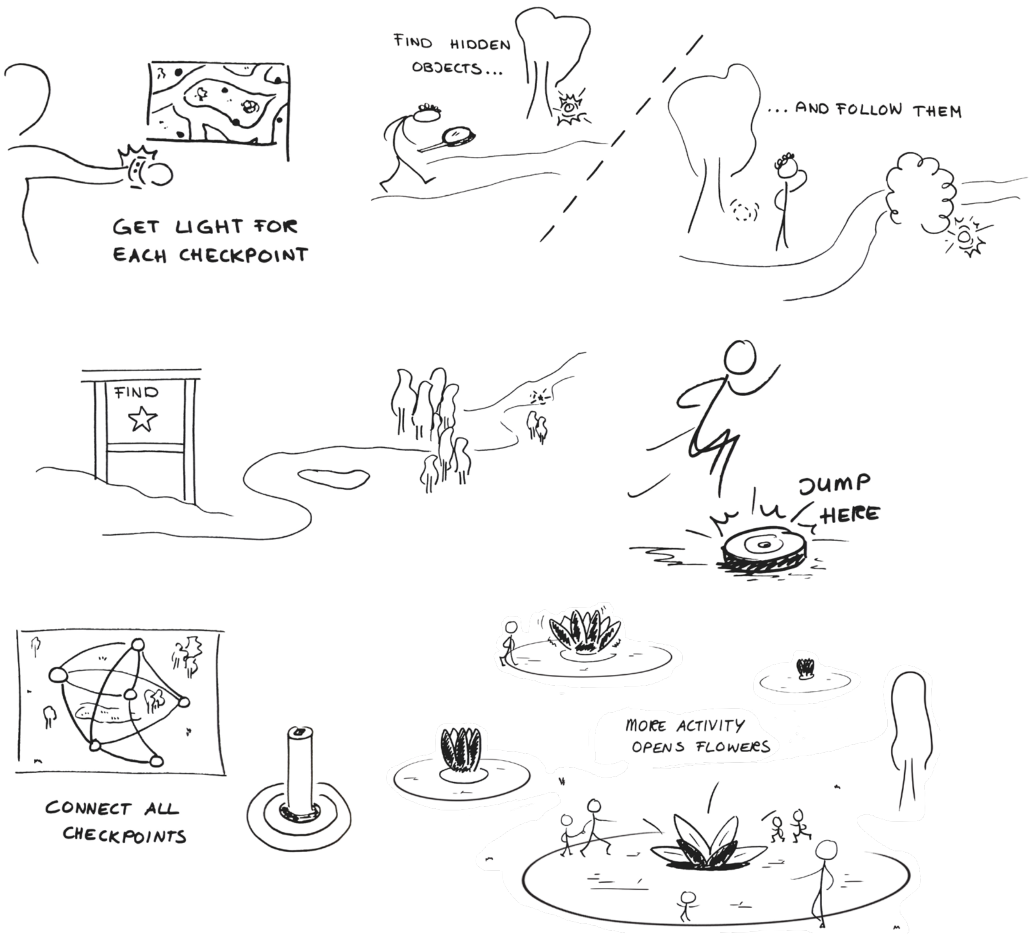


Figure 6.1: Sketch explorations.

Figure 6.2: Pilot prototype tested in-situ.

6.3.3 Pilot Test

To test the initial appeal and intuitiveness of the interactions with a device placed close to a walking route, we built a first prototype (Figure 6.2). We considered how to balance smooth integration within the landscape while still standing out enough to nudge users, and meet safety requirements. A modular system was chosen to enable full scale integration in the urban environment.

The prototype consisted of a circular LED display and motion sensors. Users could light up a circle on the surface by walking around the disk, which would stay on for 24h to show collective progress and trigger future users.

Users (N=18) could interact with the prototype and shared their experiences through a brief interview. The intended interaction was not clear to users. Intuitively, most participants wanted to step on the device to interact, instead of walking around it. They appreciated the triggered curiosity and exploration, but both the interaction and the device's feedback were considered one-dimensional and not very stimulating. Adding layered and varying interactions would likely increase curiosity and engagement. While participants appreciated the colored lights, their brightness took away from the intended subtlety and challenge of discovery.

6.4 DISCOV: an interActive Environment Intervention

6.4.1 Design Concept

We designed Discov as an interActive environment intervention, relying on existing behavior and using exploration as a nudging mechanism. Discov is a network of physical waypoints placed in a public park that encourages people to explore their surroundings in a fun and challenging way by creating an interactive walking experience. To trigger curiosity and exploration, Discovpoints are placed on the ground away from the walking path but standing out from their surroundings through their shape and colorful design. They can be spotted by park users from a distance, but to support onboarding before increasing the feeling of challenge, some are easier to find than others. Some points are placed near popular paths and areas, while others push for exploration by inviting people to quieter and less known zones of the park. The shape and color effect is amplified with lights when people approach a Discovpoint, indicating further interaction possibilities (Figure 6.3).

People interact with Discov by touching or stepping onto it. The point responds with light feedback, turning to a rainbow glow when used by multiple people simultaneously. When stepping off, lights shining out and moving away from the point indicate direction and distance to other Discovpoints. This triggers curiosity and motivation for an extended exploratory walk, without imposing a fixed route or duration, encouraging users to pursue their playful and healthy discovery journey. Through its engaging and explorative nature, Discov additionally increases mindfulness as it distracts people from their day-to-day worries by drawing their attention to their surroundings (Figure 6.4).

Figure 6.3: DISCOV prototype in a public park.

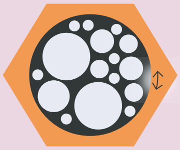
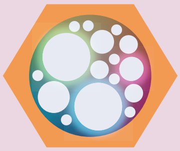
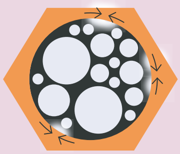
Passerby Action	DISCOV Reaction	
Approaching the DISCOV point		A light follows the passerby
Touching the circles		Circles light up when touched
Touching circles simultaneously together with a cowalker		A rainbow glow is shown
Continue to light up all circles		All circles light up
Circles are lit for 5 seconds or stepping off		Directions to other DISCOV points are indicated

Figure 6.4: Discov interaction modalities.

6.4.2 Field test

A two-stage field test was conducted (N=15) to evaluate the interaction with a Discovpoint and implementation of the waypoints network. The first part consisted of intuitive interactions with the Discovpoint and open interview questions about expectations, experience and interpretation of the design. The second part featured 5 waypoint prototypes, only showing direction and relative distance to other points, placed 100-250m apart in a park (Figure 6.5). Results showed that an initial interaction helps to let people know the device 'does something' yet keeping it vague triggers curiosity, which increases the desire to explore and subsequent satisfaction. This both lengthens and enhances the interaction. The direction indications were clear enough to hint at more waypoints to find, but the distance and multiple point signals were not always understood. Again, this ambiguity mostly added to the desire for exploration.

Figure 6.5: Field test. ▶

6.4.3 Future Work

Future work will include field deployment of multiple Discovpoints to investigate exploration behaviors in a full-scale environment. In a new version of the prototype, the points will communicate with another using wireless technology: the suggested follow-up points will thus vary based on route- or point popularity, crowd control or other variables of interest to stakeholders. By tracking the use of each point, we can determine user behavior patterns and e.g. see if Discov can attract people to less popular areas. We will also explore different interactions with Discovpoints to test their potential to engage and to see if different interactions at different points would increase impact and long-term potential of the underlying user experience.

6.5 Discussion and Conclusion

We designed Discov, a network of physical waypoints in a public park that encourages fun and challenging exploration of the environment for a more attractive walking experience. Building on the concepts of interActive environments [266], behavioral change theory [30,103], and curiosity [314], Discov triggers exploration to improve the walking experience, stimulating both physical and mental vitality.

Through this design exemplar, we researched the effect of triggering curiosity to engage in or extend physical activity, using interactive technology in the environment to relate the intervention to an existing active routine. We see potential for this approach in the large group of people desiring to walk more, yet also for passersby with no initial intention to exercise. User test findings indicate that mixed or varied interactions and ambiguity in the design can trigger exploration, which lengthens and enhances the interaction and can even inspire further usage. On the other hand, unclarity about interaction possibilities or purpose can discourage use. These findings are aligned with the role of curiosity in the explorative process [314] and the need for clarity to provide the high coping potential needed to experience interest [353]. The authors demonstrate that a good balance between obvious interactions and hidden aspects can trigger curiosity and exploration and help to engage users over a longer time.

Fitting into the existing routine of taking a walk, Discov lengthens and enriches this experience, subtly extending physical activity without it feeling 'forced'. By providing a positive experience, it even increases motivation for future walks. Using open suggestions for exploration, Discov leaves room for autonomous decisions about walk distance and duration, ensuring compatibility with varying personal schedules. Attuned to varying group sizes of walkers, Discov can be used by individuals while also stimulating collaboration when exploring together. Additionally, the design increases mindfulness and the positive effects of being in nature [47] by drawing people's attention to the momentary experience of their surroundings.

With Discov we aim to encourage longer or more frequent walks, and so help people to embed enough physical activity into their daily lives. Next to enabling and providing triggers and motivation to be more active, Discov is embedded in the physical public environment. Though a physical installation requires government and/or community investment, this approach has significant advantages, including low-threshold use and accessibility to all [264]. Being a network of modular elements, Discov can be scaled to fit a park or other public spaces, providing a harmonized experience throughout the entire area [266]. Integrating sensing and data capacities within such an interactive environment intervention can provide key insights to urban designers, municipalities or policy makers. While further research is needed to consolidate our findings, this design research shows promising use for interactive installations in the public space to encourage physical activity.

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7

Fontana

Triggering Physical Activity and Social Connectedness
through an Interactive Water Installation

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7.1 Introduction

Physical inactivity and associated health concerns are a major societal challenge in modern western societies [33,159,334]. Promoting and supporting active lifestyles is therefore a timely and popular topic in multiple research fields and public policies. Through their design, urban environments can contribute significantly to stimulate people to be more active [167,275]. We see potential for this in active environment design [90,166] and the continuing shift towards human-environment interaction (HEI) [297,306], where technology is increasingly integrated in the environment and is therefore both more omnipresent and less noticeable.

With their unique motion, plasticity and reflections, water features are popular elements in landscape design [223]. Water can be used to attract people of a wide age and background range [352], and create either a calm or exciting atmosphere [223]. Building on this knowledge, we designed Fontana, an inclusive interactive water installation that stimulates physical activity in a fun and social way. We explore and showcase the use of embedded interactive technology to promote physical activity, using water as linking element between different users. With Fontana, we contribute to research on how human-environment interactions in the public infrastructure can encourage people to be more physically active. We focus on the potential of water for designing interActive environments, and how to strengthen social connectedness while adopting an inclusive design approach.

7.2 Related Work

7.2.1 InterActive Environments

Uniting the persuasive powers of urban environment design and HEI technology, van Renswouw et al. (2021) defined the concept of interActive environments [266]. These smart environments use the combined potential of both fields to encourage people to be more physically active. With their intelligent technology embedded in the public space, interActive environments can adapt to different users or circumstances. They are accessible to all passers-by without any prior investment, including those who are not deliberately trying to change their inactive lifestyle. This makes them more inclusive than other technologies to increase physical activity [266]. Examples of such environments aimed at triggering healthy behaviors are Discov [265] or Sensation [264]. Discov is a network of interactive waypoints placed in a public park. By triggering curiosity and exploration they provide a fun and challenging walking experience [265]. Sensation is an interactive path that matches natural sounds to people’s footsteps to provide a more enjoyable and relaxing environment [264].

In-context use and effects of such interventions can be studied using a research-trough-design approach [358], specifically the Experiential Design Landscapes method [205]. This design research method takes the design process into people’s natural, everyday environment using smart probes to learn about user behavior as can be seen in the Social Stairs project [245]. This example of an interActive environment with a strong social component was installed on a staircase in a public building, persuading people to take the stairs rather than the elevator. Next to increased stair use, the researchers found a distinct social engagement that encouraged even more active behavior, such as jumping and dancing, and attracted more users. A second iteration rewarded social behavior with a richer, more dynamic sound experience. The social aspect added to both 'trigger' and 'motivation', which together with 'ability' are the main factors needed for behavior change to occur [103].

7.2.2 Designing with Water

From village wells to impressive statements of vision, power and identity, water features have combined and provided spaces for social interaction and sense of belonging throughout urban history, 'sustaining' communities [300]. Water is also rich in symbolic and religious values [185]. This explains the attraction of water features over different cultures and the varying social activities taking place around them. They are therefore effective design 'tools' when creating collective social space [300]. Next to their visual and social appeal, water features also provide a multisensorial experience and increase the pleasantness of an environment. Water plays with light and shows wind or vibrations on its surface [185]. Its distinct soundscape can mask unpleasant noise such as traffic [110], and running water causes a cooling feel while helping to accelerate ventilation and remove traffic fumes, providing a fresh smell [352].

Designing with water requires dealing with its dynamic nature, multisensoriality and the special relation people have with this element [185]. Attraction parks often include water games or water shows as their most popular family activities. But even rather simple interactions can evoke surprisingly engaging experiences [65]. Think about the playfulness of walking in the rain, jumping in puddles or splashing in water. Many art installations also play with the fascination created by water. In the Rain Room by Random International (2012) visitors are simultaneously exposed to and protected from the water falling all around with a rain effect. Through the use of 3D tracking cameras, visitors experience the sight, sound and smell of rain as they navigate the space, while still remaining dry [255].

We reviewed several publications describing the design process of interactive water installations, which use water as an organic or embodied interface [65,114,126,241]. Authors report playfulness as a core element of the user experience [126,241], with water interfaces reminding people of both the risk and thrill of children's water games [114]. At the same time, water can be used to emphasize association with nature and create holistic and multimodal experiences [65]. Nasar and Lin (2003) measured human responses to different types of water features. Although both still and moving water features are perceived as pleasant, there is a preference for jets and combined features, which are also regarded as most exciting [223].

Curiosity can be an important motivator for interaction [290,314], as can be seen in the public installations City Mouse, placed on a public square in Oulu city, Finland [126] and Water Games, featured at the Universal Forum of Cultures event in Barcelona [241]. For both designs, participants were exploring options and interactions, desiring to figure out the different interaction opportunities. Supporting this exploration and discovery can further amplify the curiosity of participants and so keep them engaged longer [265,290]. The City Mouse and Water Games installations each allowed multiple users to interact simultaneously and even to work together to reach a common goal. This shows the potential of water installations to effectively facilitate social interaction. Both installations also demonstrate the attraction of such water features; Water Games had a high number of users per hour compared to other interactive installations mentioned in their paper and City Mouse engaged and attracted users from all age groups, though more children actually interacted with the installation.

7.2.3 Inclusive Design

Public spaces and services benefit greatly from inclusive design principles, because they are meant to be used by anyone [63]. For this work, we therefore aim to adopt a user-aware design approach; pushing the boundaries of 'mainstream' to include as many as possible, regarding users with divergent requirements as 'normal but different' [63,296]. Eliminating barriers enables inclusive use, while at the same time displaying progress towards social justice [296]. Designers therefore need to understand desires of a wide range of user groups and respond to this diversity [296]. For older people, for instance, good designs can help to maintain or improve physical independence, yet factors as reduced sensitivity, hearing and vision need to be acknowledged. Messages and interactions should therefore not rely on one sense, but rather a combination of modalities, such as audio and visual signals [63]. As emphasized in the Microsoft Inclusive Toolkit [211], "disability happens at the points of interaction between a person and society. Physical, cognitive, and social exclusion is the result of mismatched interactions. As designers, it's our responsibility to know how our designs affect these interactions and create mismatches." Inclusive design is key to address permanent disabilities but also temporary and situational limitations (e.g., a parent holding a baby, thus not having their hands free).

Simultaneously, designers cannot create without barriers, because they are inherently part of the physical –and virtual– environment. Creatively approaching these existing barriers to realize enabling environments is thus an important goal in inclusive design practice [296]. By removing barriers and including different user groups, inclusively designed interactive installations also provide the opportunity to increase social connections and to support collaboration between these groups. A social component can create a richer, more fun (interactive) experience. Working together will enhance the sense of inclusivity while increasing understanding and empathy between different user groups.

7.3 Design Process

Combined with our literature study, we reviewed engaging public installations as source of inspiration [266]. Analyzing their design principles, we found that social interaction and collaboration are important elements in the success of these types of installations. As many existing interactive public installations are targeting children, there is an opportunity to expand their reach by designing for a wider age range [266]. We also observed that installations mostly focused on able-bodied people, excluding those with special needs. We decided to focus our design process on inclusivity, aiming to prototype an engaging and playful installation which could be used by a variety of users.

7.3.1 First Explorations

We explored the solution space through sketching potential solutions, some of them revolving around the interaction with water (Figure 7.1). Inspired by the concept of public installations triggering social interactions, we included playful collaboration features.

To increase our understanding of inclusive design, and empathy for potential target users, we placed feedback requests in five Facebook groups, including three groups for people with disabilities and/or elderly people and caregivers, a group for designers and a general audience group. Based on a short description and visual impression, we invited people to comment on what an interactive public water installation to trigger physical activity would ideally look like, and what to consider for their specific needs as a potential user. This included the overall concept, types of interactions they would prefer, issues they predict, specific needs or design requirements and additional open feedback.

Key takeaways included the importance of safety, such as using anti-slip materials where necessary and providing clear distinctions between wet and 'safe' areas to prevent unwanted stimuli or panic, but also adding calm spots to enjoy the spectacle. In line with literature, respondents also suggested to increase clarity and accessibility by using multiple types of in- and outputs; triggering multiple senses by including sound, light, color and varying textures; and different kinds of fountains to attract a broader audience.

We created a small-scale prototype to get familiar with technical aspects, interaction and output of such an interactive water design. Too small to conduct a representative user test, this prototype along with a rendered video impression of the concept was presented to 10 design experts with backgrounds in HCI- and industrial design to gather feedback. Important insights were a high preference for more diverse and complex interactions, and exploring and implementing effective, engaging ways to create an inclusive experience, specifically compared to regular fountains or splash parks for children. This also resonated with the conclusion of our initial benchmark exploration, which showed limited examples of interactive environments for target users of all ages. Experts also stressed the importance of considering that the degree to which people actually want to get wet when interacting with a water installation varies a lot for different user groups or use contexts.

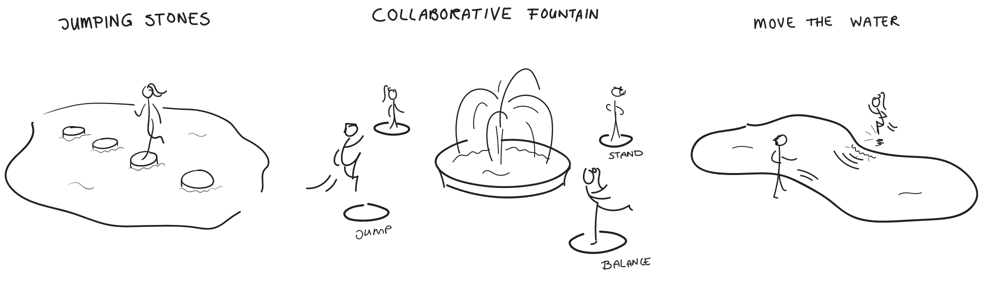

Figure 7.1: Examples of sketches using water as an interaction modality triggering social connectedness.

For instance, it might be acceptable during a summer day at an attraction park, yet less so when commuting to work in the morning or when weather conditions are not adequate. In line with the inputs we gathered from the online groups, this can be addressed in the design in several ways: giving the impression of water without the risk of getting wet (as in the Rain Room described in Section 7.2.2 [255]), playing with aspects of water that do not involve wetness (reflection games, skimming stones), including a sort of progression in how “splashy” parts of the installation are, or simply by clearly indicating dry and wet areas.

7.4 Fontana

Fontana is a prototype of an interactive public installation that aims to stimulate physical activity and social connectedness in the urban outdoor space, using the multidimensional attractiveness of water. Through different interaction possibilities and inclusive design principles, it targets users with a wide age and diversity range, encouraging them to work together. Building on the ubiquitous attraction of water features [185,300], Fontana uses water as a universal, fun and inspiring design element to connect people and encourage physical activity.

The design consists of multiple fountains and pressure sensitive floor tiles on a hard flat surface. Users can interact with the fountain by stepping, jumping or rolling over the tiles around the installation. As Fontana is meant to be an interactive environment in the public space, anyone present should be able to participate, making inclusivity an essential design goal. Fontana accommodates different users by including several interaction modalities. The pads respond to jumping and stepping as well as strolling over or tapping on them. The pads are clearly recognizable through their color, circular shape and waved texture. Additionally, accessibility is optimized by keeping the installation level with the surrounding area.

7.4.1 Pilot Study

To explore how users engage individually and in shared encounters [156], we used an iterative prototyping process. As a first iteration, a simplified prototype was built using a submerged pump with a height control valve to generate and control the waterflow of a single, small fountain. We used convenience deployment [156] and a Wizard of Oz setup, simulating the interaction by manually controlling the height and power of the fountain (Figure 7.3a). Since this setup only entailed one fountain, the collaborative use was rewarded by repeatedly turning the fountain on and off several times. Observations were made and noted using guidelines for live observations [118]. Afterwards, participants were interviewed to learn about their experiences and other feedback to improve future iterations.

The onboarding interaction was perceived as unclear. Participants (N=12) were confused about what to do, some not even noticing the interaction pads. Only one participant spontaneously approached the fountain and started interacting, the others first came to us for clarification (n=5) or were invited to participate (n=6). With only a slight difference between single and collaborative use in this prototype, groups showed disappointment or confusion when collaborative synchronous use did not give the expected output. Overall, the groups interacted longer than individuals, but

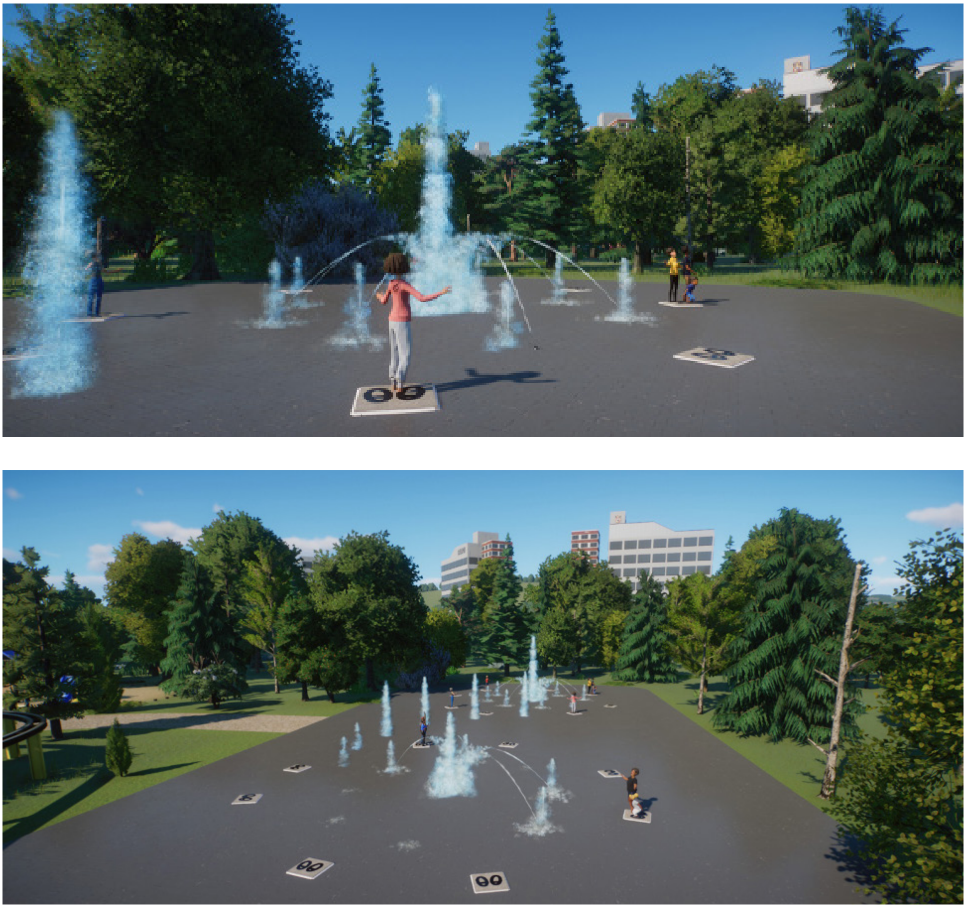

Figure 7.2: Fontana concept impression – render created in Planet Zoo [107].

none stayed engaged longer than five minutes due to limited possibilities. Participants additionally indicated that the interaction pads and entire setup should stand out and be more inviting, clearly showing interaction possibilities to engage passersby.

To further explore the user experience, we conducted a pilot study with an improved prototype with semi-controlled deployment [156]. All participants were adults (N=19), including 5 older adults, and representing mixed cultural backgrounds. The main aim was to evaluate three interactions: onboarding, repeated interaction and synchronized collaborative interaction (Figure 7.3b). The new prototype included a much stronger fountain, which was remotely controlled by pressure sensitive floor tiles. The fountain was surrounded by three tiles as interaction points. Again, observations were made and participants were interviewed afterwards.

For this iteration, onboarding happened spontaneously, with passersby stopping to try out the prototype and exploring different interactions. Most participants (n=11) showed excitement when

Figure 7.3a: Pilot test setup: first iteration Wizard of Oz setup.

the fountain responded to their inputs. Groups (n=9) naturally started synchronized use after first having some individual interaction. Interestingly, participants were not just interacting with one tile; they were also frequently changing between tiles. Two groups of participants invited friends to join in, but none of the participants invited strangers to join. Due to the different interactions to be explored, users stayed engaged longer than during the initial test, with sessions lasting around 10 minutes.

From both the observations and interviews, we see that the fountain sparked exploration and imagination. Participants enjoyed the freedom and playful exploration to find out what was happening and were enthusiastic about the concept and possibilities. Looking at the difference between both tests, we expect that using more fountains or other techniques to show varying outputs for different types of interaction will further stimulate exploration and imagination of users, lengthen the interaction and encourage collaborative use. One important comment around the idea of inclusive design was that the tiles were decorated with footsteps used as nudges to indicate that

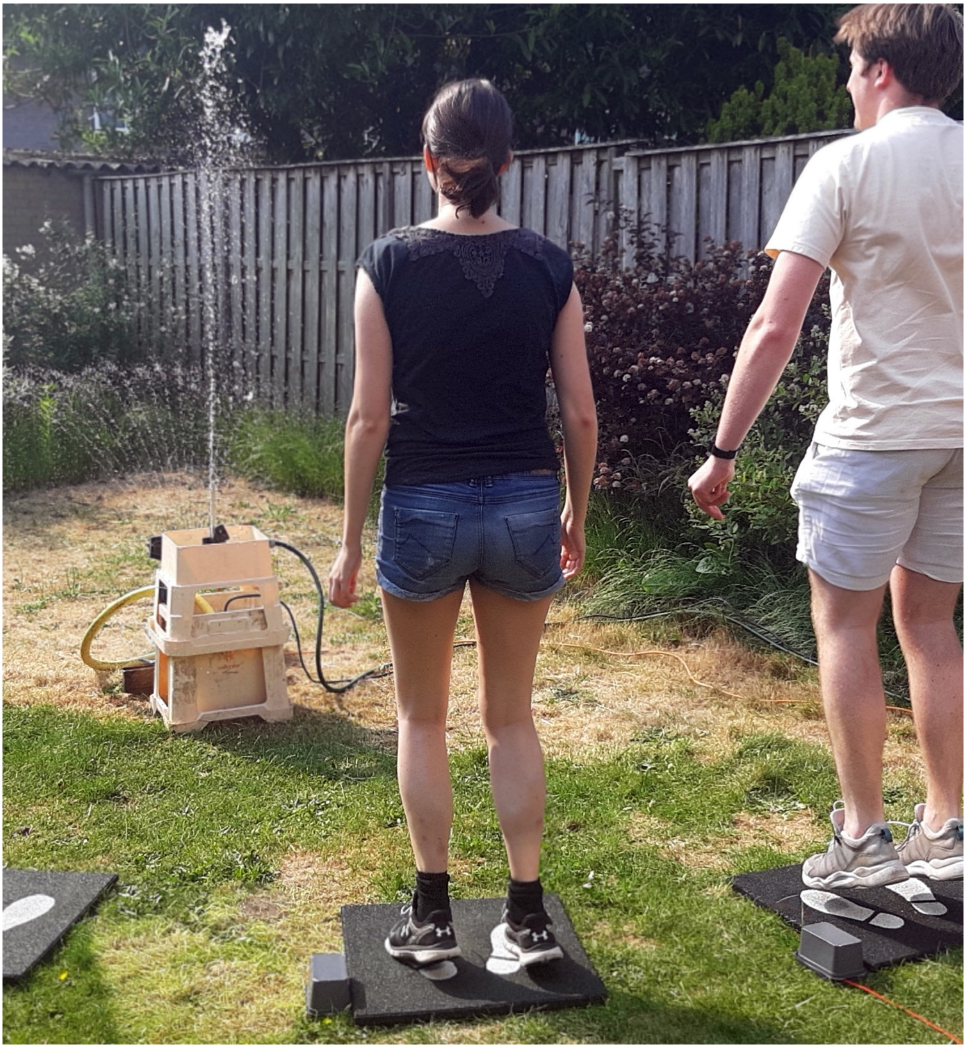

Figure 7.3b: Pilot test setup: synchronized interaction with second iteration prototype.

the tiles were offering the possibility to step on. However, these footsteps might for instance not look inviting or inclusive to wheelchair users or a parent with a stroller. A reflection on how to represent inclusivity in our nudge is needed: what we aim for is that people understand intuitively that tiles would react to stepping, jumping, or rolling on them.

7.4.2 Interaction Scenarios

Based on the pilot studies and design explorations conducted, we defined several interaction scenarios for the next prototype of Fontana. Several layers of interaction accommodate different types of users and stimulate both individual use and collaboration (Figure 7.5). The varying feedback and increasing difficulty of collaboration can also help to engage users for a longer time [50].

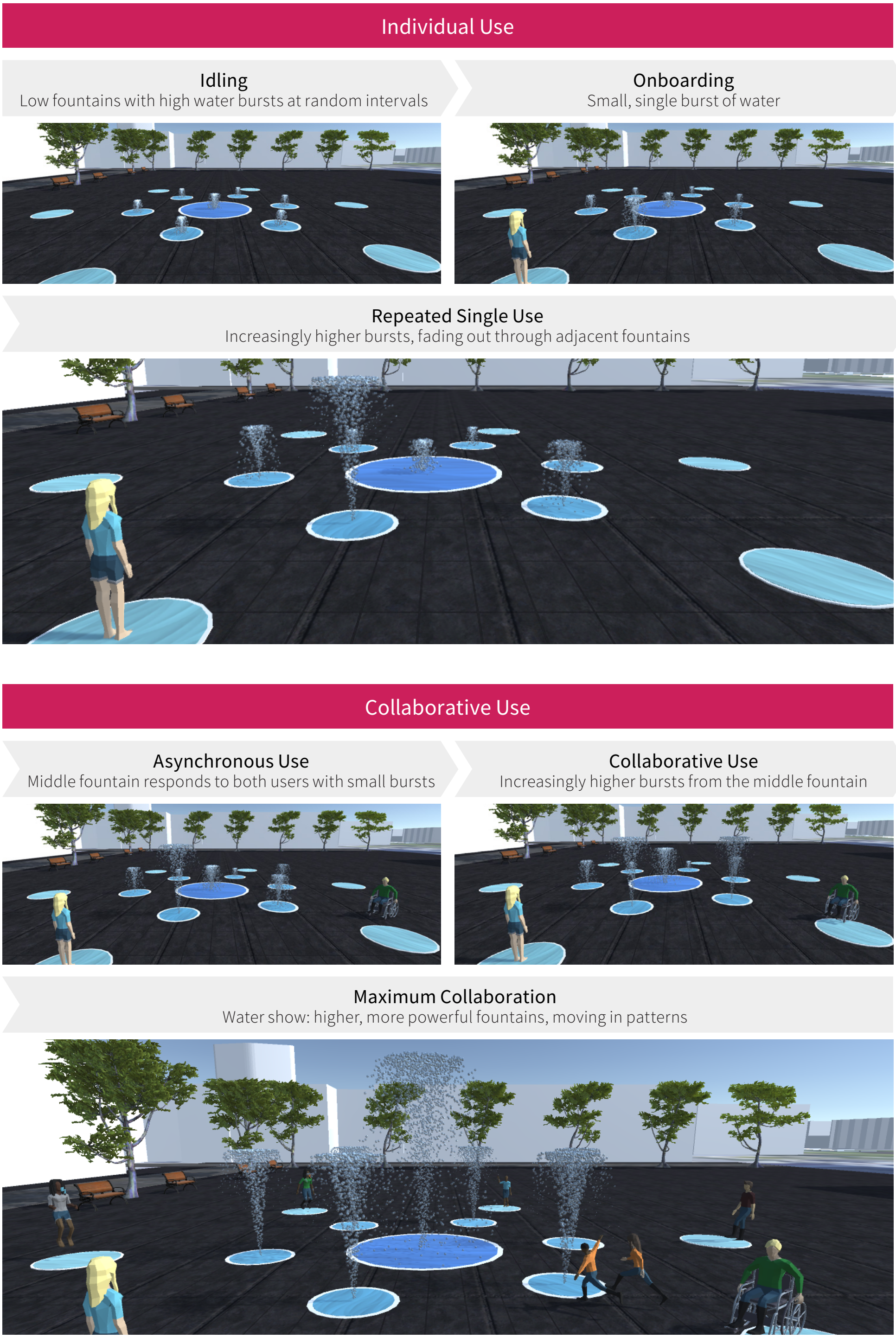

Figure 7.5: Fontana interaction scenarios.


6

7.5 Discussion and Future Work

InterActive environments can play an important role in encouraging physical activity through their design and ability to adapt to different users or circumstances [28,266,297]. Since they are also more accessible than other available solutions [266], these environments provide a good base for inclusive design solutions. In this research we therefore focus on the use of embedded interactive technology to promote physical activity, combined with inclusive design practice.

While existing interActive environments often target a specific user type, such as children or sporters [266], we focus on including users of a wide age and diversity range by using inclusive design principles. We designed Fontana, an interactive public installation that uses the attractiveness of water and playful elements to encourage physical activity and social connectedness in the urban outdoor space. Through Fontana, we research the potential of using such a physical, environmentally embedded installation when designing for behavior change, and specifically the use of water in this context. With this design we aim to encourage playful interactions, and so help people to embed enough physical activity into their daily lives. Next to physical activity, the installation also stimulates collaboration, which potentially enhances the interaction, lengthens the engagement, and most importantly brings together different user groups. This in turn strengthens social structures and inclusivity.

From our explorations we saw that small adjustments –such as indicating 'safe' and wet areas– can strongly impact the inclusivity of the design. This shows that empathy for and involving people with different needs in the process is essential when designing inclusive environments. While aiming for universal inclusivity, awareness of the existing barriers that inherently come with each design is also an important mindset [296]. For Fontana, while already including users with a wide age and mobility range, limitations still exist for people struggling with social situations or strong stimuli. In our future work, we will continue involving people with varying needs to further increase the inclusivity.

For the next stage, we aim to use the Experiential Design Landscapes method [205] to explore the behavioral effects of Fontana on social connectedness and physical activity through in the wild deployment [156], collecting additional data from the pressure sensors. This allows unobtrusive study of spontaneous user and passerby behavior in a real-life setting which is essential to research our assumptions about user engagement and social impact. It will also help to include a broader audience, with participants of different ages and degrees of disabilities. This is important to test and improve the designed inclusivity features. Though short-term collaboration with strangers is a first and easily observable step towards social connectedness, long-term implementation and observation would be needed to indicate actual increased social coherence as well as possible novelty effect.

We will further iterate on input and output modalities, ensuring an inclusive character of the design and exploring effects of different types of fountains or other water features as well as different types of nudging to embed the notion of inclusiveness. Reviewing both permanent and situational limitations systematically using the Microsoft Inclusive Activities toolkit [211] will further contribute to our investigation and the quality of the final design.

Acknowledgements

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part III

Perspectives on Data

Smart solutions provide increasing quality and availability of data, both in the fields of HCI and urban design and planning. Though these developments offer exciting new design- and research opportunities, they also bring challenges for designers as they interlace these disciplines. At the end of part I, we noted two main opportunities to increase the positive effect of active urban environments by capitalizing on the potential of using data and interactive technologies. In part II, we investigated the possibilities of interactive solutions for active environment design. In this third part, we now look into the challenges and opportunities presented by the growing wealth and availability of data in this context. We therefore investigate how we can use –and regard– data to address the challenges and opportunities that arise from working at the intersection of disciplines when creating interActive Environments.

In chapter 8, we explore the value of user-generated big data for urban planning of active and healthy public spaces. Based on running data collected by two popular apps in The Netherlands and Belgium, we present three iterations that set out to gain understanding in what factors define good running environments. The first iteration uses data visualization techniques to get geographic insight in our data, to identify running hot spots and other points of interest for further analysis. The second iteration uses a mixed method approach to combine running data with qualitatively scored environmental characteristics of the selected locations from iteration one to identify possible influencers of the attraction of these areas for runners. To enable further scaling in the third iteration, we explore how we can come to factors that are worth scoring. Creating a larger set of locations with a reduced number of variables allowed for more substantial statistical analysis. This approach helped to provide an initial insight in the relevance of some of the environmental factors for optimized running climates.

In chapter 9, we investigate how user-generated big data can support designers in shaping more activity-friendly and adaptive environments, addressing both timely challenges. Bridging the fields of HCI and urbanism, we introduce two data lenses. The individual lens primarily builds on empathic design skills and calls for a highly personal approach. The collective lens emphasizes systematic and holistic design skills, focusing on creating overview and surfacing collective interests. Through exploratory data visualizations, using the same user-generated running dataset but combined it with public data sources, and a workshop, we investigate how these lenses can yield meaningful insights for the urban design and HCI communities and address the challenges and opportunities that arise at the cross-section of these perspectives.

Urban Planning for Active and Healthy Public Places with User-Generated Big Data

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8.1 Introduction

Our society is facing a noticeable increase in sedentary behavior and physical inactivity, which is a growing public health concern [33,323,332]. Policy making for public environments to promote healthy and active lifestyles is a contemporary topic in both government practice as across multiple disciplines in research (e.g. interaction design, urban design, geography, sociology and psychology [108]). There is ample evidence that individual, social and environmental factor influence physical activity levels and behaviors [23,64,122,173,194]. Furthering one of the grand societal challenges of increasing physical inactive lifestyles in most of the western world, the research fields see this trend being influenced by how the space around us is shaped [333].

In this chapter the focus will be the role of the physical environment in promoting physical activity, as research has shown that characteristics of built environments are related to rates of chronic disease. More specifically, physical activity is perceived as a critical mechanism in this [23]. Because physical activity in urban areas often happens in public space, local and national governments can provide focus on the health values through their urban planning. Although larger cities and metropoles have not necessarily developed keeping these values in mind, health oriented environments stimulate the wellbeing, happiness and welfare of the people using it [275].

The purpose of this chapter is to explore the possibilities of user-generated big data for the urban planning of active and healthy environments, with the ambition of providing recommendations for physical activity policy making in the future. We explore these possibilities by means of a case study of recreational running in urban areas. Today, running is one of the most popular sport activities with 50 million participants in the EU-28 [41]. Moreover, running is an expression of the exponential growth of unorganized sport practices in urban areas and parks, which require no or limited specific infrastructure [38,324].

Where, how, and why people run is notably influenced by urban layouts. In this chapter we aim to create an insight in the extents of this influence, using GPS trail data collected via a popular running app among novice runners. We will discuss how this type of user-generated data can or cannot contribute to defining what makes a good running environment and by extension what factors are important for the optimization of existing public spaces for a better running climate.

To give better insight in the policy context of this research, we start by outlining the context and purpose of this study. Building on these, we describe the approach we used to get insight in how user generated running data could be relevant for the urban design of public spaces. Through a combination of data visualization techniques and exploratory data analysis we present a series of iterations that gave us insight in the value of user-generated running data for urban planning. Through three iterations we show how we have been looking for factors that influence the quality of running environments and how this can be valuable for policy making of public places. We approach this from an urban design perspective and involve big data to research its potential benefit for this discipline. Finally, we discuss the qualities of running-app data with regard to designing for urban spaces and outline future steps for this research.

8.2 Policy and Research Context

The research is situated in and focuses on the city of Eindhoven, located in the south of the Netherlands. Eindhoven is the fifth-largest city in the Netherlands, with a population of about 223,000. Eindhoven pursues to position itself (internationally) as an innovative and sports minded city, focusing both on attracting elite sports and on providing ample good quality sport facilities and public areas for leisure time sports [61]. The city government largely controls the development of sport-infrastructure itself. Three areas have been appointed with a specific focus on the provision of mass sport and physical activity opportunities. Each of these areas has its own management which guards the integration of nature, sport, art, culture, education and recreation. The three sport areas are to be connected by the 'Green Y', a Y-shaped combination of natural green areas in Eindhoven [61].

The further development of the provision of mass sport and physical activity opportunities in Genneper Parken is the research context for this study. Over the last 30 years, this public park, one of the three areas of interest for the city of Eindhoven, has been developed into a recreational sports park that is well balanced with other urban characteristic (e.g., ecological structure, original landscape, historic village) [113]. The focus on sport and recreation was already mentioned in local development plans in 1988 [60]. Since then, multiple local strategy planning documents have confirmed and maintained this focus [60,254,330]. Evidently this is an area that received extensive attention with regards to sports and upon observation we clearly recognize these qualities.

The city of Eindhoven considers participation in recreational running as an important goal in their sport policy. Indeed, the promotion of running in Genneper Parken is considered to be a powerful tool to stimulate participation in sport and physical activity in Eindhoven. In this chapter we use user-generated big (running) data to unravel which qualities make up for a good running environment and what other implications access to this data could have for urban planning of public spaces.

8.3 Method

To investigate the role of user-generated big running data, this study utilized data from two popular running apps (for less-experienced runners) in the Netherlands and Belgium. One of the advantages of running related smartphone applications is their ability to track behaviors over time in the daily urban environment [324]. Start2Run (STR) [93] and Hardlopen met Evy (HME) [94] (translated Running with Evy) are running apps that intend to motivate people to start running by providing training schedules and feedback and offer them insight into their running patterns. In essence both running apps are identical, as they share the same owner EnergyLab [95]. STR is positioned for the Belgian market and HME for the Dutch market. Both apps are only available in Dutch.

The data collected from the app consisted of full GPS trails for each run (1.5 million runs in total). On top of these run trials a metadata set summarizing these runs is available. This summary data includes a run- and user-id, timestamp at the start of run, duration, distance, average speed, effective time (duration from start to stop minus the pause time) and training id (if a specific training session provided by the app was followed).

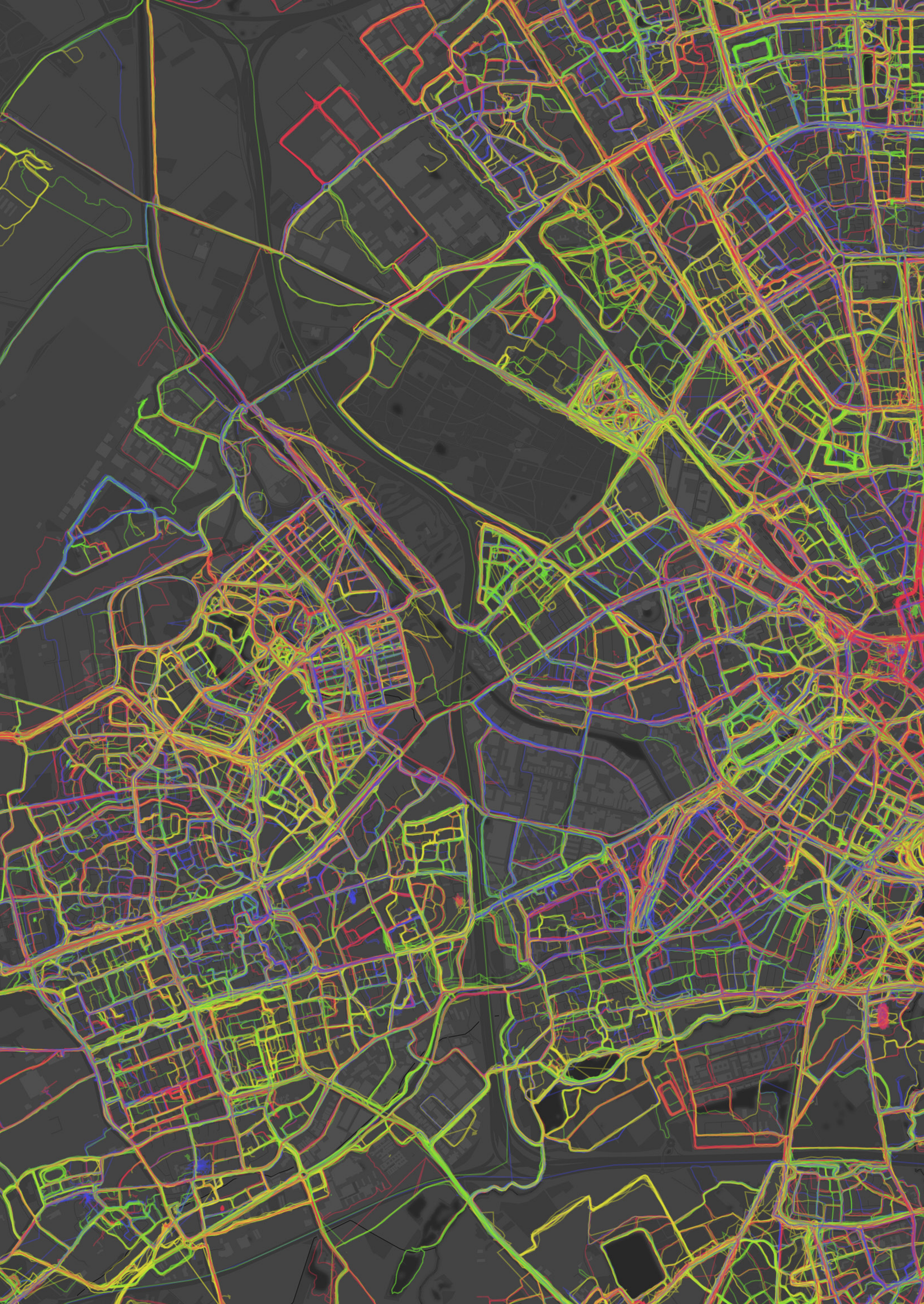
To explore how this data can be relevant for urban planning and design of public environments, an iterative approach was applied. In a first iteration (interactive) data-visualization techniques were used to get grip on the quality of our data and to understand basic geographic characteristics of runs. Besides taking a geographic (collective) perspective, a side step was made to exploring what insights an individual runner's perspective may bring us. Based on insights from the first iteration, the second iteration revolved around characteristics of quality of urban running environments. A mixed-data source approach was used to analyze a selection of twenty running locations, based on city level visualizations. Both running-app data and qualitative checklist-data were combined.

Via the qualitative checklist, a set of variables was scored for each of the locations. These variables were: possible running distances, running surface, background soundscapes, green or natural environment, (artificial) light, accessibility, signposting and state of maintenance.

In a third iteration we tried to scale this further by comparing 271 handpicked running spots in the Netherlands (NL) and Belgium (BE) to generate a set of focus features as input for a future extended and more in-depth mixed method approach.

Figure 8.1: Heatmap of Belgium, colored by daily time clusters.

Figure 8.2 Heatmap of Antwerp and Ghent.



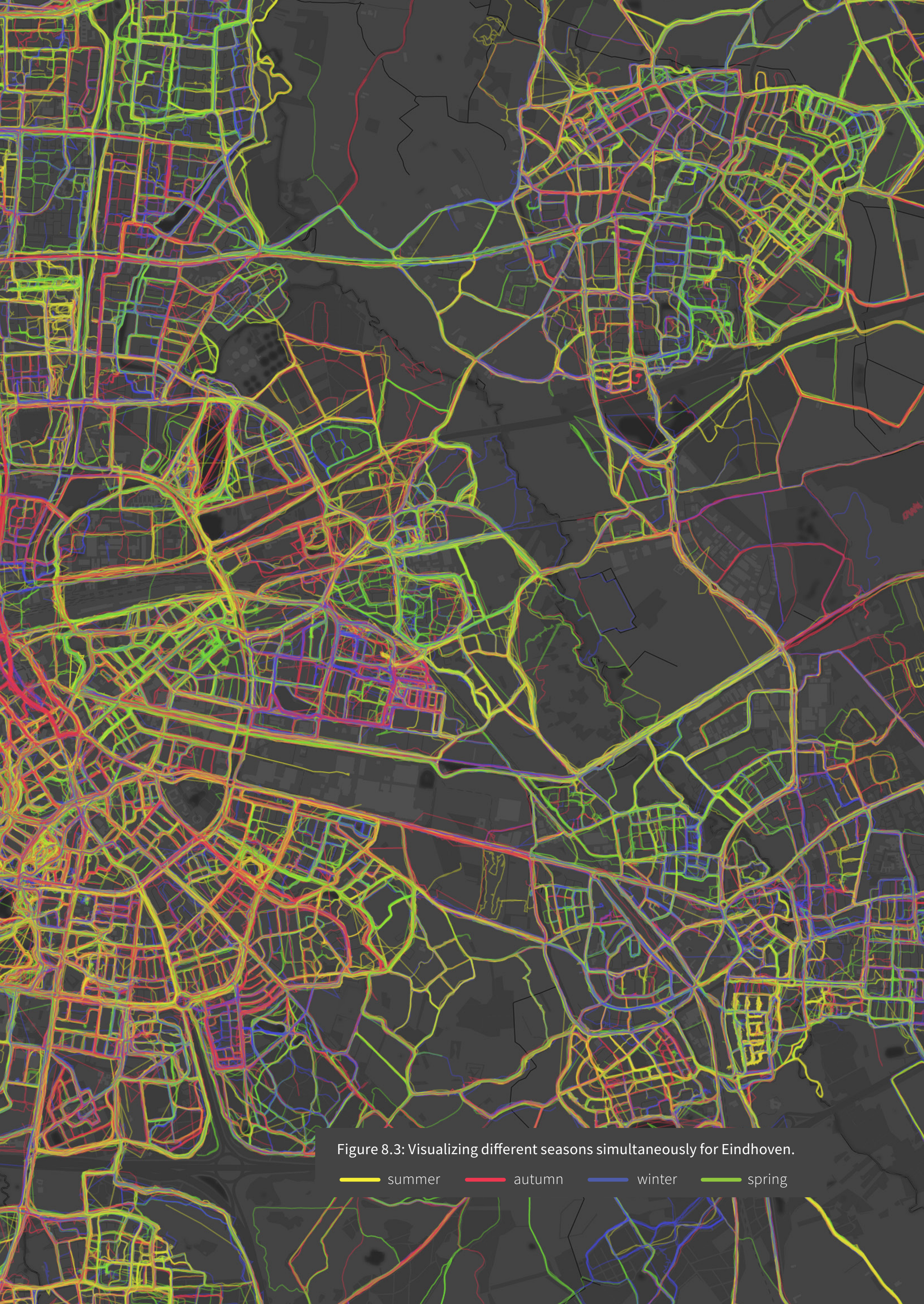


Figure 8.3: Visualizing different seasons simultaneously for Eindhoven.

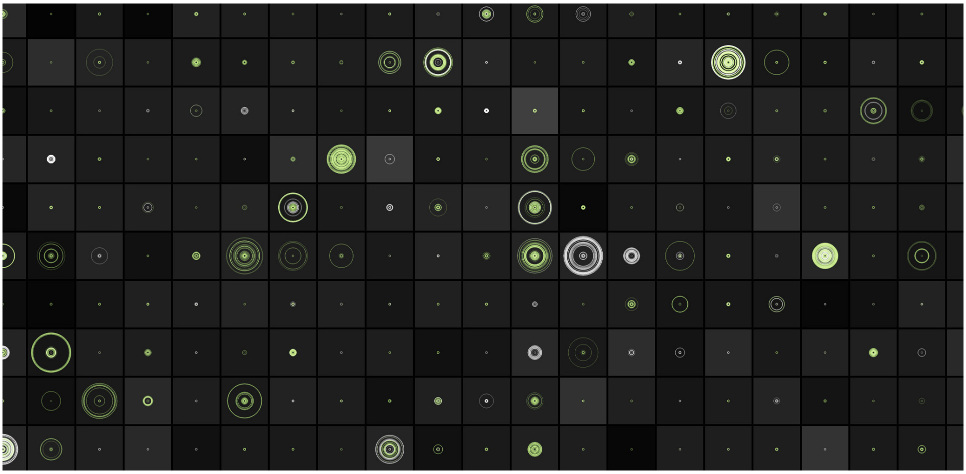


Figure 8.4: Visualization of running routines per user.

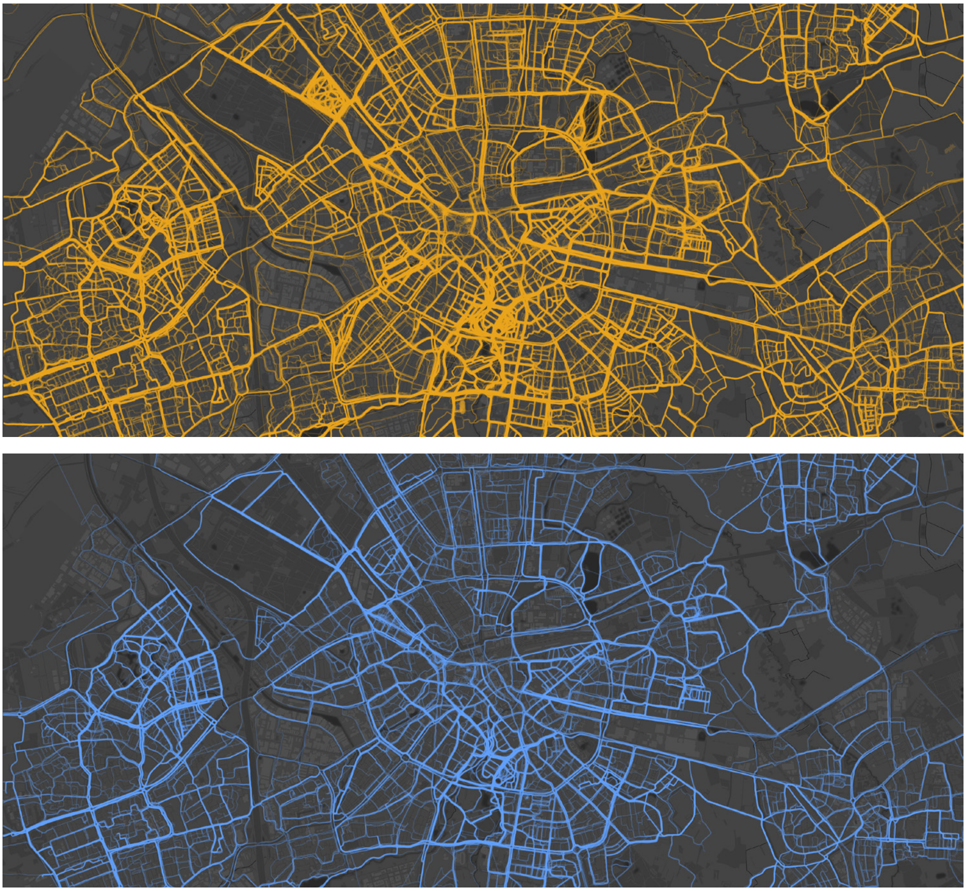


Figure 8.5: Heatmaps of Eindhoven region before sunset (left) and after (right).

8.4 Results

In total the dataset contains 1,490,145 runs since 2012. Exactly 40% of these runs is created by the Belgian version of the app (STR). Of all runs only 76936 (5.2 %) is located outside NL and BE, forwarding the clear geographical focus. Overall runs have an average speed of 8.0 kilometers per hour with an average distance of 3.9 kilometers. Compared to the Amsterdam data of the popular app Strava [303] this is 23.5 % slower (10.45 km/h) and 53% less far (8.2 km). This is a clear indicating these apps focus on less experiences runners; a different target group. As we approach this from an urban planning perspective we first explored the data to get insight in the geographical distribution of the runs. Outlined below is a description of activities of the three different iterations, combined with insights that connect these iterations.

8.4.1 Iteration 1: Data Visualization

Based on the starting locations of each run, a geographical overview was created (Figure 8.1). Next to the aforementioned available metadata of these runs (e.g., start time, duration), each run was given a number of additional attributes (i.e. daily time cluster (morning, afternoon, evening), the day of the week and the month it was ran). Comparing these location based starting point visualizations, that show these characteristics (either color-coded or only showing fitting runs), provided a first insight in running behavior that varies over time. Differences in quantity between varying types of runs were clearly visible (e.g., more summer than winter runs), while the relative geographical spread was hardly affected by these distinctions. To have more detailed insight in how this changed on a city level, we merged the full GPS trails with the metadata to create city level heatmaps that showed all running trails in the selected cities, instead of just the starting position (Figure 8.2). Again, extra attributes were calculated and added to the dataset. (i.e., season, week or weekend, daylight or dark based on sunrise and sunset times). This made it possible to visualize the GPS trails combined with the running metadata (Figure 8.3). These heatmaps were created for five different cities in NL (4) and BE (1). Based on the runs located in these areas, metadata was calculated and added to these maps (i.e. total distance, amount of runs, unique users, average speed).

Next to these location centric visualizations, user centric visualizations were created. Figure 8.4 visualizes the running routines of 750 (random) users. One square is dedicated to each user. The circles represent a run, the distance between the circles is depending on the amount of time in between these runs (like the year-rings of a tree). When a training exercise from the app is followed the circle is colored green, otherwise it is colored white. These simple visualizations enabled us to quickly visually compare the running routines of different users, to see the time interval between runs or structured routines. These individual patterns added additional information which can be relevant the urban planning of public spaces.

The running heatmaps of all cities clearly highlight green and natural environments. Comparing daylight and night-time runs, reveals significant differences in running patterns. Indeed, these visualizations show that most of these 'green' locations lose their attraction after nightfall. Of course, lack of artificial lights and safety will be a defining factor when explaining this difference, but there may well be others. Where during the daytime the parks are the clear hotspots in the city, at night these hotspots move to streets in residential areas (Figure 8.5). This contrast can have a variety of possible causes. It could mean that people choose to run closer to home later in the evening, that the 'green' environment loses its attraction when it's dark out or that the difference in social control and 'feeling safe' between a night-time park and a night-time residential neighborhood is important to runners. Even though the data might tell us something about how these spaces are used by runners, it contains little information about why people act this way.

The user centric visualizations give a slightly better insight in personal motives as it differentiates individual from the group. Keeping some of these individual run characteristics in mind we decide to focus our next iteration on the location based approach as our prime interest is in the environmental characteristics.

8.4.2 Iteration 2: Mixed Data Source Approach

The first iteration, using heatmaps and running statistics from the database, showed a clear difference between the use of parks and other natural areas and more urban running sites in (and around) the city. Finding out exactly which environmental factors play a part in causing this distinction would be a great step towards determining what makes a good running environment and thus provide valuable insights for urban planning for active and healthy public spaces. This second iteration therefore had a mixed data source approach, focusing on collecting environmental characteristics of twenty running locations and comparing these with the running data from the app.

The city level visualizations were used to select interesting running spots in the cities. For these areas more detailed and zoomed in heatmaps were created, again accompanied by area-specific statistics. To determine if runs classified as being on a certain track, we used a two-step approach. All running locations were described by a tightly fitting bounding box. Runs that had a starting location less than 10 kilometers away from this bounding box were selected. For these runs it was verified whether one of their coordinates would fall inside the inner bounding box.

The tracks were qualitatively and manually scored on environmental characteristics, using a simple checklist to keep the observations as objective as possible. Through statistical analysis, we then combined this qualitative scoring with the collected GPS trails to find factors for optimal running environments. Based on Pearson linear correlation coefficient calculations, there are a few interesting potential influencers. A correlation was found between the number of runs on a track and the average speed there. Also, the maximum distance of a track (being the maximum distance that can be run without repetition) appears to influence not only the number of runs, (and with that the total distance run) but also the average distance.

Although some indications of relevant factors came forward from this iteration, they were not so distinct that a total of twenty scored tracks was enough to draw solid conclusions. An initial insight in future focus-areas is gained but additional data, especially concerning the environmental characteristics and preferably also qualitative experience data, will have to be collected to really understand and break down environmental influence on running behavior.

8.4.3 Iteration 3: Running Location Analytics

Iteration 2 clearly highlighted the need for more contextual and experiential data to understand which qualities are influencers of good running environments. This iteration therefore sets out to get further insight into environmental elements that could be influential by expanding the set of evaluated locations and reducing the number of scored attributes.

In this study we are interested in factors that can be influenced by urban design. For instance, if a longer distance track turns out to attract more runners this is something we can influence. If people only run in good weather this becomes harder to influence; unless influenceable factors are at the heart of this (e.g., slippery or muddy surfaces). To gain more insight into these factors we manually marked 271 running tracks; 87 city parks and 184 'Finse Pistes'. A 'Finse Piste' (bark running track) is a man-made, looped running track, covered with a soft top layer of woodchips or tree bark [38]. The city parks and 'Finse Pistes' have different characteristics and within both categories locations also greatly vary. Based on the full GPS trails we clustered runs to the marked locations. All 'Finse Pistes' are looped. To determine which runs took place on such a track only runs coming within a 200-meter radius of the center coordinate were added to the set. Instead of pre-defining factors we hoped to find outliers in running tracks. In a next step we could then qualitative analyze running tracks across a spectrum to define new factors to score.

The shown correlation diagram (Figure 8.6) is a first experiment to see how variables in our set are related. There are expected moderate correlations between variables, for example the time of the day (i.e., morning, afternoon, evening) and whether it's a Monday to Friday or a weekend run.

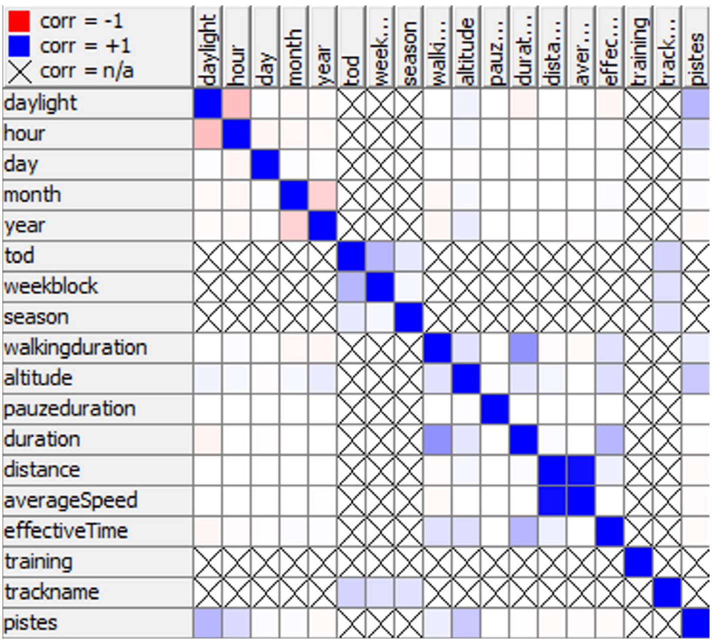


Figure 8.6: Correlation diagram of environmental attributes.

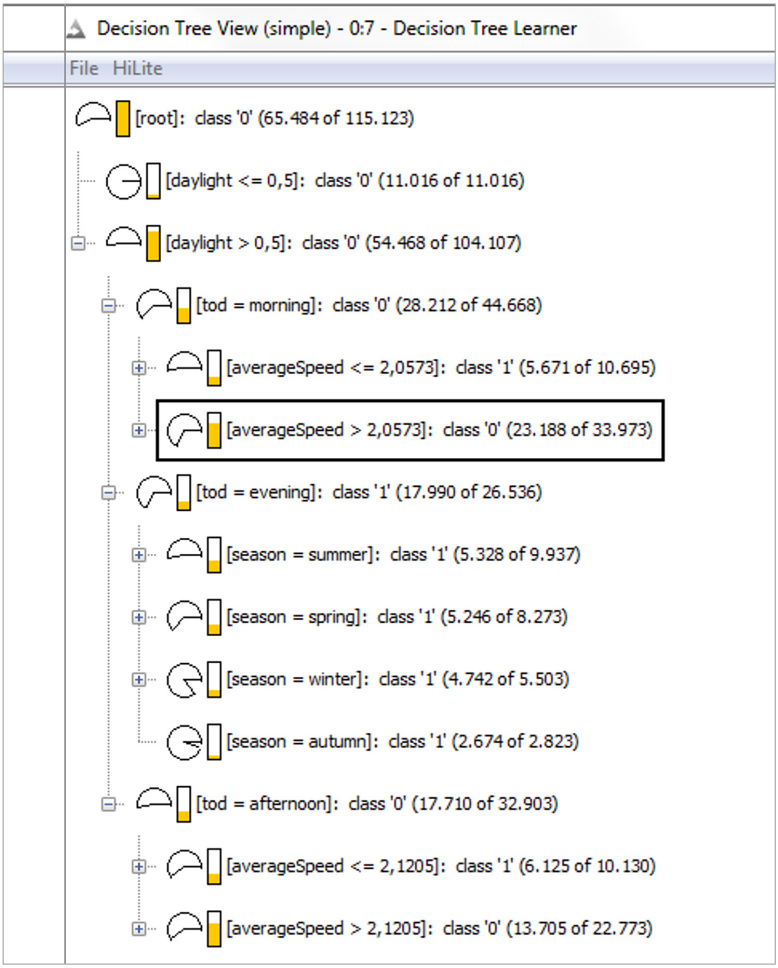


Figure 8.7: Outcomes initial prediction model.

Comparing the 'Finse Pistes' with the city park tracks, we note that on average app users run 0.59 km/h slower on the 'Finse Pistes' than city parks. As we know these locations to be focusing on novice runners and have a different surface, this matches our expectations.

Next, they were compared in an initial prediction model (decision tree learner & prediction (Figure 8.7)) to investigate if there are strong differences in characteristics between locations. The purpose of this was to see if the track could be predicted based on the other attributes. Aside from a strong predictor that later turned out to come from incorrect and therefore misrepresentative daylight variable, this experiment showed little strongly predictive values. Future repetition of this experiment with correct daylight information could therefore potentially still show predictive value for this attribute.

8.5 Discussion and Implications

This study explored the possibilities of user-generated big data for the urban planning of active and healthy environments, and providing recommendations for physical activity policy making. The results show that from this data green and natural environments in cities can clearly be identified as running hotspots, showing the attraction of these areas on runners. A notable difference between daylight and night-time runs however, shows that this attraction only lasts during the day. These findings are in line with the findings of Borgers et al. (2016) [38] who show that a good light setting is a primary condition for people to value running tracks. Additionally, interesting potential environmental influencers for the attraction of green areas for runners are found, including the maximum uninterrupted length of a track.

To make user generated big data relevant for urban planning additional information about contextual and experiential factors is needed next to the GPS and meta data from the running app. The iterative approach of data visualization and analytics proved an effective way of zooming in on the data and it's promising attributes. As a first step in the process of determining important environmental factors for an optimal running climate, in urban areas, it provides first insights and a broad foundation for further research.

This data used for this study has some limitations which have to be pointed out. Since the data was collected using a specific running app, we must note that not every runner is using this app, and the users are at most roughly evenly spread out over the inhabitants of Netherlands and Belgium, never exactly. App users might not always take their phone when going for a run, so there could actually be more runs than registered. Finally, this app targets novice runners and is therefore likely to have a higher percentage of starters than the actual running population in the Netherlands and Belgium. Because of the amount of data collected, however, it still gives a realistic insight in societies running behavior and preference for running locations.

Contrary to the large quantity of running data collected from the apps, the number of qualitative data collected about the running environment at the chosen locations proved insufficient for a credible conclusion. For this data to provide real insight in the exact aspects of public space that attract or repel runners, more running spots would have to be scored. This issue came from the absence of environmental information in the app data.

In order to determine exactly what environmental factors influence running behavior (and maybe even to which extent), the dataset needs attributes concerning that environment. As mentioned before, this data was manually collected later, on a much smaller scale, while including a short questionnaire or even just a location-score element in the app could generate lots of these data, provided by the runners themselves.

The use of squares around running locations to determine the amount of runs there was good for this rough first insight. It is suggested that in future research the location boundaries will have to be followed more closely to be able to give exact data. In this study the focus was on different city parks. A run would be connected to a park when one of its running locations would fall inside the bounding box of that location. In the first iteration we showed a more user-centric approach. In the future it would be of interest to focus on how individuals behave differently in different environments. It would be interesting to research what deviations from structured routines are caused by, and if environmental factors play a role in this. If different runs have a different path or terrain, what is the difference between these runs (e.g., do people mostly run longer, faster or more uninterrupted in parks?) This way it could be possible to exclude more unknown factors from our models to better understand the nuanced impact of specific environments.

Making visual representations of the data made them instantly insightful for the research-team, and proved to be very useful when presenting findings and proceedings to the other involved parties. It also turned out to be an effective way of checking whether there were 'strange things' happening in the file-writing process, and runs with incorrect data could often easily be spotted. In a more in-depth study of this data and or topic there will also have to be corrected for several factors, e.g. for the size of the running location; the amount of inhabitants of the city; amount of nearby residents with some of their characteristics, and the number of runs per park.

Although the prediction model from the third iteration was a small exploration to find qualities of running environments on a larger scale with limited concrete insights, we see clear opportunities for continuing this step in the future. In the last examples we tried to predict which park a run situated in, based on a set of variables. This predictor aims to do this for all parks in general, not for specific parks. Focusing further on detailed scenarios might give us more insight in which factors influence good running environments.

During the study, the research topic proved much broader than initially thought. Every iteration, new insights raised new questions. This made the process both very interesting and somewhat unpredictable.

Especially running statistical analysis was challenging, because instead of trying to find relations between given elements, where we were actually looking for the elements that might have a relation, which were not necessarily present in the dataset yet. On top of this we were primarily looking for elements that could be influenced from our urban design perspective. The combination between qualitative analysis through visiting parks, looking at running routes at different locations and data analytics proved a value approach to advance in this.

In the 'Policy and Research Context' section we described the background of this study and our initial interest in the Genneper Parken, as one of the focus areas for urban activity of the city of Eindhoven. An already well-developed area, with regards to sports and activity, which challenged (and keeps challenging) our research to use running data to find sweet spots for improvement. Throughout our analysis we have seen clear indications for the importance of running environments that provide uninterrupted running experiences. By using the user-generated running data, we aim to better understand how this contributes to a good running environment.

However, we noticed that larger parks are the host of longer runs and we have seen that longer runs have a higher average speed (i.e. more experienced runners). Although the three active environments in Eindhoven are geographically connected in a Y shape, this is not necessarily visible from our heatmaps. Through small but innovative solutions, as green zones for runners [204], we hope to be able to better connect these areas to shape a better running environment. While we further investigate how this data can help us in better understanding these running environments, a long-term partnership with the city of Eindhoven has been established to further analyze user generated big data, in combination with survey data and observations, to support their policies for active and healthy public space.

Acknowledgements

We would like to thank Energy Lab for making their running-app data available for this study.

Changing Perspective on Data in Designing for Active Environments

This chapter is a reproduction of the paper:

Loes van Renswouw, Sander Bogers, Carine Lallemand, Pieter van Wesemael, and Steven Vos. Changing Perspective on Data in Designing for Active Environments. *under submission*

9.1 Introduction

Sedentary behavior and physical inactivity are an increasing public health concern [33,92,134]. The majority of people are aware of these health risks, but it remains difficult for them to actually embed enough physical activity in their daily routine [159,190]. Finding effective ways to encourage people to be more active and to help them to maintain a healthy lifestyle is thus a critical endeavor for researchers, practitioners, and governing agencies [159,257,334].

There is growing evidence that the design of urban environments is contributing to physical inactivity and underlying health concerns [82,166,275]. In the field of urban design and planning, the topic of designing 'healthy places' is well-researched, both in relation to general health conditions [21,42,108,180] and to physical activity [90,162,263,275]. Over time, design recommendations and guidelines have been developed to help guide this process. Regarding physical activity, these guidelines often include mixed land uses to preserve a human scale and ensure proximity of facilities, improved pedestrian and bicycle infrastructure and high-quality places for sports, play and leisure activity [3,90,320].

Despite this body of knowledge showcasing the benefits of 'healthy places' and providing guidance on how to build these, other matters, such as convenience and vehicle flow, seem to have taken priority in designing urban areas [108,117]. As a result, urban areas are often arranged in ways that are more likely to have negative health implications. While through their design, these environments have the potential to contribute significantly to physical activity levels [42,275].

Next to increased awareness for the design of healthy cities, we see a distinct shift towards 'smart city' technologies and design. 'Smart Cities' are defined as being or containing 'smart environments', building on data to optimize processes and sustainability. This data flow is used to learn and address the challenges that come with urbanization and population increase through Information and Communication Technologies (ICT) and related technologies [289]. Smart cities aim to advance performance, efficiency, sustainability, to connect the physical, social, business, and ICT infrastructure [13,131], and to increase and maintain quality of life [201,289].

This transition towards technology-enhanced environments creates a bridge between the urban design and HCI domains. HCI in turn evolves to the realm of physical space through the ongoing shift towards Human-Environment Interaction (HEI) [297,306]. In this field of research, technology is increasingly integrated in the environment and is thus both more omnipresent and less noticeable. Through their embedded technology, these smart environments provide new interaction possibilities. This offers potential for more adaptive environments that can be dynamically tailored to the user and their context, based on the wealth of data it can collect. In view of creating places that not only enable, but even encourage a healthy lifestyle, it is worthy to note that a tailored approach is a significant element in persuasive technology [28,85,147]. Environments that can adapt to accommodate users individually therefore have an increased potential to inspire healthy active behavior.

The ambition to move from static to interactive and adaptable environments has considerable implications for how these spaces are being designed [305]. No longer are static one-type-fits-all solutions required that can withstand changes of many variables over time. Instead, designers can now think about how environments can be made to adapt to circumstances like weather conditions, specific scenarios of use, the users themselves or the temporality of people's experiences. Data plays an instrumental role in these smart environments as it is the fuel to drive such solutions [160]. However, data as a dynamic enabler is not yet a standard topic of attention in the urban design field. While data is increasingly used for analytical purposes, the opportunities it presents to play a key role as a design material [160] throughout the process are still mostly untapped.

With this work, we investigate how both fields can leverage each other's strengths as we study how both a collective and an individual perspective on data are valuable when designing for adaptable environments.

9.2 Related Work

Designing healthy environments has a longstanding history in urbanism [105,180,186]. Smart city and -environment developments introduced a technology and information layer to that, which bridges it into the HCI space. Within the HCI community, an opposite parallel trend is also clearly visible in the growing body of research on Human-Environment Interaction (HEI) [297,306]. The transition from 'artifact' to 'environment' has several implications for the dimensions of user experience. For example, transitioning from usability to comfort or from short-term relationships with products to durable and immersive experiences [7]. Following the narrowing gap between these two design fields, our objective is to bring perspectives from these communities together in our exploration of how user-generated big data can be valuable in designing for adaptive active environments. To do so, we outline different uses of data in urbanism and in human-computer interaction.

9.2.1 Data in Urban Design and Planning

Next to their use of data and technology to optimize processes and sustainability, smart cities are characterized by being inclusive and able to adapt to the behavior of their inhabitants [20,247]. This makes human- and user-centered design approaches for future cities highly relevant and extremely important [297,305]. In order to design these inclusive 'cities for all', being aware of the real citizens' use of the public space is therefore essential [247], making crowd dynamics a popular research topic in the field of urban design and planning [18,55].

As such, people have become an important resource in the process of creating this new generation of cities [109,247]. Through visiting living lab areas, sharing their data or other forms of conscious or unconscious involvement, the inhabitants of these cities provide valuable input for governments and urban architects alike [111]. On-site sensor kits for single point measuring give clear insight in a specific situation without requiring active participation of citizens, while richer, more complex data can be collected by aggregating user-generated data. This data, collected through apps or wearable technology from many different users, can provide relevant insights about the population in general [260].

As this data is connected to specific people or objects, it enables more longitudinal observation. This allows urban architects to understand complex behavioral patterns such as specific transport streams or activity behavior, eventually supporting informed decision-making for urban planning and design [260,323].

In most cases these user-generated big data sets focus on specific topics (e.g. cycling data), but smart systems expand on this by integrating a wealth of additional data of varying type and source to find meaningful patterns [106]. We note that data is currently being used dominantly for analytical purposes, informing design and decision making as evidence or by driving predictive models [10,137].

Visualizing these data collected from citizens can be a powerful tool to both get and communicate such insights [49,123,287]. Earlier work on the value of visualizing user-generated urban activity data to assist urban planners in creating healthy or active environments found this approach promising, but additional data or details may be needed to make effective use of the sensor data [20,62].

Reflection

Big data has come to play a more important role in the urbanism practice, with new ways being explored to capitalize on the stream of data coming from smart city solutions. When creating new policies or spatial designs, planners, policymakers and designers typically consider and value the general trends, patterns and averages provided by the aggregated data [227]. Traditionally, this approach makes a lot of sense. Since there would be only one static and lingering space (or policy) that affects many people, the focus lies on 'the average person' so that the design is likely to be suitable for most. But if the definition of a 'smart' city is that it is not static, but can adapt to its resident's behavior [20], involving only the 'average' citizen in the design process seems a little short sighted. We argue that if cities and environments grow to be adaptable, they should be able to adapt on a more personal or individual level. Data plays an important role in enabling this adaptability. As it is essential for digital technology to register, learn from and respond to human behavior, we need data to both understand and help shape human behavior in urban environments.

9.2.2 Data in Human-Computer Interaction (HCI)

As a more digital discipline, the use of data is essentially a core concept in HCI. It is the fuel to drive smart or intelligent systems as it is a key ingredient in personalization solutions [222], recommender systems [242] and adaptive interfaces [27]. There is an increasingly prominent focus on data in HCI research and practice [155] as the shift towards more intelligent systems makes it one of the key materials to design with [160].

Of particular interest in the smart cities context is work that revolves around personalization and adaptivity. Here, smart or intelligent artifacts collect data about user behavior and the context they are in, to adapt their own behavior accordingly [282,321]. For example; a smart baby bottle that gives different feeding advice based on the caregiver [35] or an interactive pedestal that can adapt its behavior based on the people in the room and how they are interacting with it [81]. There is ample evidence from the persuasive design community indicating that personalized solutions are more successful in achieving long-term behavioral change [28,85,147].

The focus on data as a material is valuable in this regard. For the system to understand who the user is, or what spatial setting it is in, it needs to collect data that can embody meaningful stories [59]. Focus on details, nuances and people's idiosyncrasies prevails over generic insights on population-level [170]. This means focusing both on finding denominators as well as focusing on what makes people unique. Data visualizations that aid in this progress therefore also address being able to compare user behaviors, between different moments and between different people. In this area of design research, small datasets and explorative data visualizations are typically used to gain highly individual insights because larger datasets are often missing at the front-end of innovation [293].

Next to the focus on data as a material to design with, we see increasing use of data to drive and inform design decisions [155]. Similar to the common approach in urbanism, in these cases data is mostly used to analyze existing or created situations, based on which decisions can be taken. The data that is being used is not the data that drives these systems, but an additional layer of analytics data that gives detailed insights in the situation. These insights are based on what the majority of users prefer, which could limit its' inclusivity and diversity [63]. Different data-design approaches have varied roles for decision-makers. In data-driven design, results from experiments directly drive decisions. In data-informed design, there is a larger role for the decision-maker, who weighs their personal knowledge with the insights provided by the data [155].

Reflection

In order for a smart environment to encourage people to be more physically active, a tailored or personalized approach to this persuasion would likely be most effective [28,85,147]. User-generated data offers a unique opportunity here because it holds detailed, often long-term data about user behavior. These behaviors can be contextualized with more environmental data that can also come from other sources. The key is to focus on individual traits and characteristics as this is essential in gaining the empathic understanding that is needed to design systems that can really adapt to people's individual needs. Explorative data visualizations, with high levels of individual detail, have proven to be a valuable tool in this [231,287].

9.3 Research Objectives

In this chapter, we investigate how research in the fields of urbanism and HCI can be combined to create meaningful perspectives on user-generated big data. The urbanism perspective provides reliable insights in general behavior and trends, a large-scale and birdseye perspective. This view is still rather unexplored in HCI literature [4] and introduces challenges of scale and accompanying inflexibility unfamiliar to the HCI community. On the other hand, the more individual and personal perspective that is thoroughly embedded in the HCI mindset is often lacking in the urban design context. This view that is typically adopted on a product or interaction level in HCI may have been impractical in the past for designs of urban scale and lifespan. Smart city developments, however, are likely to benefit from a more personalized view towards data.

We therefore set out to explore how both fields can leverage each other's strengths as we study how both perspectives on data are valuable when designing for adaptable environments. As we feel these views should not be limited to one field or the other, we introduce two lenses that we investigate through a case study.

By introducing a *collective lens* on data, we aim to emphasize the value of the urban population perspective that is needed to design for an adaptive active environment. Topics like socio-cultural patterns, geographic and environmental characteristics, and collective trends could potentially be addressed by this lens. To do that, this lens focuses on aggregates, common denominators, and repetitive patterns. The collective lens could be used to build a solid foundation that benefits the population in general –the collective– when designing adaptive environments.

We introduce the *individual lens* on data to celebrate individual uniqueness. It is a perspective that values detailed knowledge about individual users in order to investigate how people are different and what makes them unique. Being able to capture these idiosyncrasies would be instrumental in further tailoring the adaptive environments to individual needs. The individual lens could be used to investigate individual preferences and patterns, and the role of external factors, to accommodate users on a more personal level and acknowledge them as human, unique parts of the whole.

We deliberately propose the terms *collective* and *individual* instead of *macro* and *micro* to address these perspectives to emphasize not only the scale but also the human-centered focus that's at the core of our approach. Similarly, Afonso et al. (2019) also use *collective scale* and *individual scale* when describing ways in which we experience the city, before switching to the terms *body scale* and *city scale* to accentuate interactions with outdoor interfaces [4]. Micro-macro models are used for a wide array of concepts to indicate scale, with micro-level representing the smallest unit of analysis and macro level the largest. These lenses describe a specific subset of these levels; they articulate a focus on experience, desire and needs of people, either as an individual or as a group. All other entities, both of a tangible and intangible nature, that influence or are otherwise relevant for that purpose are collectively addressed as context.

To investigate the value of these lenses we conducted two studies; We started by exploring the value of both perspectives through a case study of user-generated data from a popular running app. We focused on running as a well-documented example of conscious physical activity taking place in the urban environment, building on the knowledge that environmental characteristics considerably influence running behavior [82]. Through a series of data visualizations, we explored different ways in which urban data can be combined with other data, and how they can be visualized to yield meaningful insights for their respective perspectives. To test the potential of the lenses we then invited other professionals to use them in a design workshop, using the most auspicious visualizations of the first study to present the data for both lenses. Based on these explorations, we discuss the qualities of the collective and the individual lens, the interplay between these lenses, and how designers can leverage them while designing for adaptive environments.

9.4 Study 1: A Case Study Of User-Generated Running Data

9.4.1 Research Approach

In our endeavor to explore ways to design a new generation of healthy environments, our focus in this study is on the value of the *collective* and the *individual* lens. Specifically how we can use the data that is collected through smart systems or environments to improve the design or design process of such places.

As a case study illustrating this approach, we use data collected through a popular running app. The individual and independent nature of running makes it hard to track these sporters in a traditional, centralized research setup. However, through increasingly popular personal activity tracking apps and devices, many recreational runners log their own activity; collecting valuable data often over a longer period of time [142]. We analyzed a large set of this kind of user-generated running data through both lenses to find valuable insight for the design of healthy environments.

For the collective lens, we start with an urban perspective, exploring how we can use data to enrich that perspective; looking for new or more details, specific information of certain areas or other valuable insights. Next, we adopt an individual lens, looking at the same data from a different perspective. Rather than looking at general trends, here we look at what makes specific users unique, stand out from the crowd, and how we can use exactly these insights in the design of (adaptive) environments. The exploration of the lenses was a highly iterative process. The process and insights are merged into one section to accommodate the documentation of that process.

9.4.2 Dataset and Data Visualization Tools

For our study we used a dataset collected by EnergyLab's popular Dutch running app, called *Start2Run* in Belgium [93] and *Hardlopen met Evy* in The Netherlands [94]. These apps primarily target novice runners yet are also used by runners with more experience. They can either be used to track any run or to provide training schedules and audio guidance during runs. Both apps are identical apart from country-specific branding.

The dataset contains detailed GPS trails (approximately 5-meter accuracy) of 1,490,145 runs, collected between 2012-2016, and for each run a set of summarizing metadata, including a run- and user-id, start time, duration, distance, average speed, effective time (time of the run minus pause time) and, if applicable, training-id (relating to a specific training program provided by the app).

We use explorative data visualizations to uncover patterns and gain insights into user behavior [231,287]. After processing and cleaning the dataset, we visualized it using a combination of visualization tools. Early explorations made use of the d3.js [39] visualization library. As this gave performance issues with the vast amount of data we transitioned to the use of open-source mapping platforms MapBox [195], TileMill [84] and later the webGL powered Deck.gl [319]. For the visualizations for the individual lens we again used d3.js. As we could select a limited number of users, data size was less of an issue here.

9.4.3 Exploring the Collective Lens

First map-based data explorations

To emphasize the urban and macro approach of this lens we started our explorations with map-based visualizations. Our first one was a map that visualized the starting point of each run from the Start2Run app on the Belgian map (Figure 9.1).

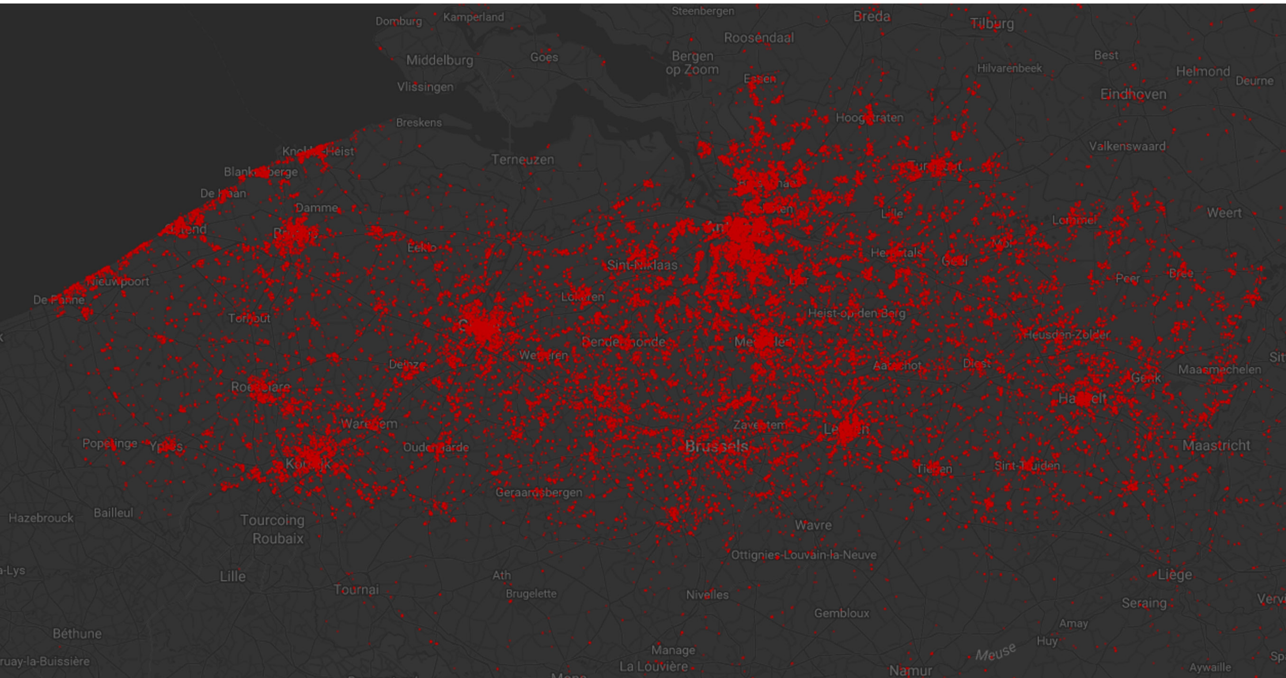
This gave first insight into the geographic spread of our data, and already clearly articulated more and less densely populated areas. The map covered a large area, arguably even beyond what urban planning and design is usually concerned with.

As a next step, we added a few color filters to the interactive visualization, allowing us to filter on the time of the day (i.e., morning, afternoon, evening), the day of the week, and the month of the year. This showed how people were less likely to run on the beach in December than in May and that there was often more activity on a Sunday morning than on other moments during the week. Although it was good to see general assumptions being confirmed by the data, there were not many novel insights. We concluded that this data visualization was zoomed out too far to meaningfully capture our collective lens.

Understanding (un)popular places

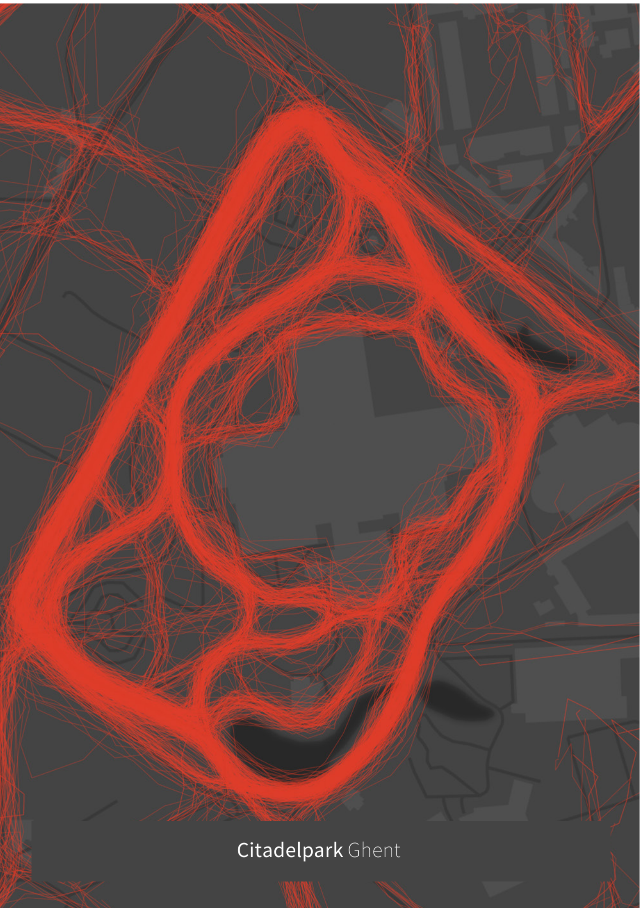
In new visualizations, we zoomed in further to the level of cities and areas that made sense to address from an urban planning and design point of view. At city level, it became eminent that we needed more granularity than only the starting location of each run, as that said little about popular running areas; only where people started their activity. On this scale, we added the full run trails to the map.

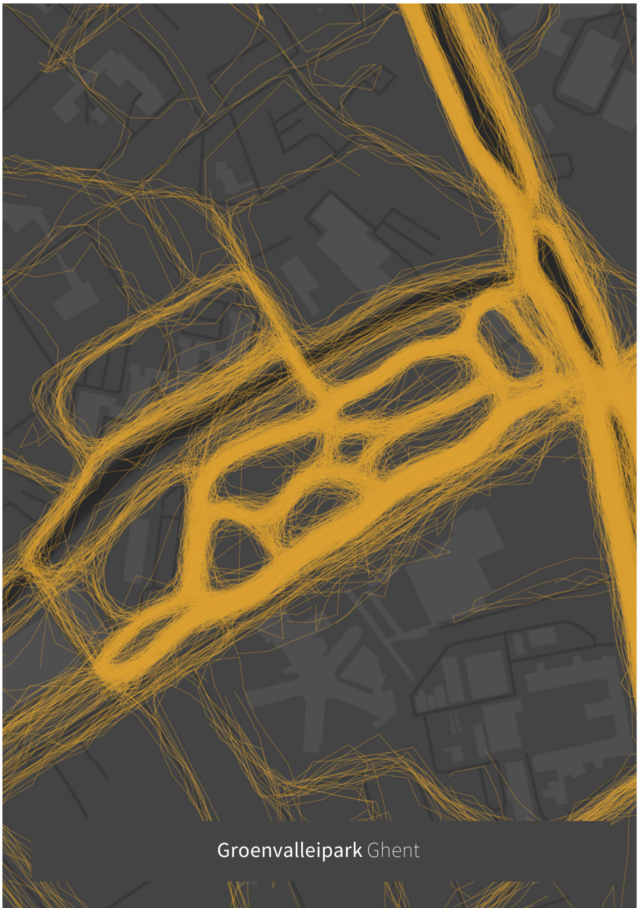
Figure 9.1: A map visualization showing all Start2Run runs in Belgium. Filters can be used to change the meaning of the colors (i.e., time of day, day of week, or month of year).

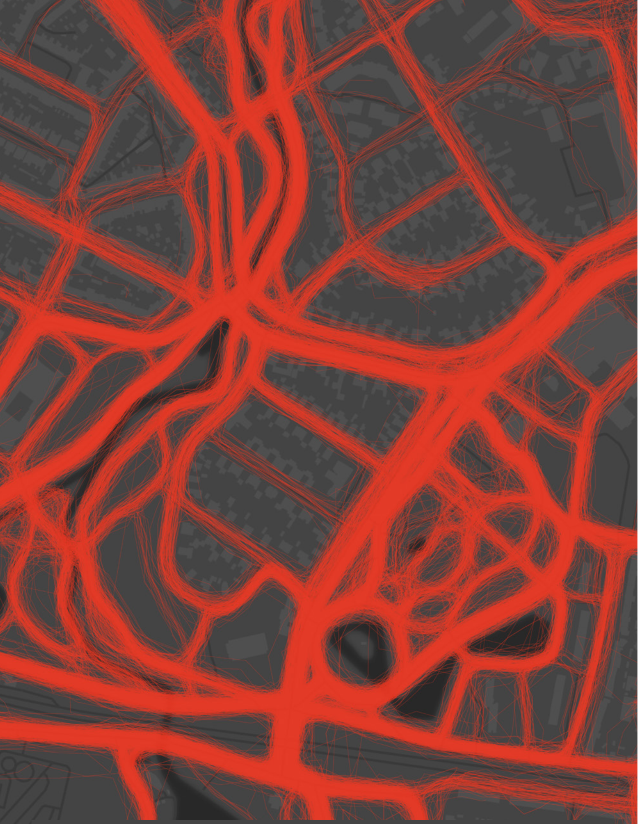



Philips de Jonghpark Eindhoven


Severijnpark Genderdal Eindhoven


Citadelpark Ghent

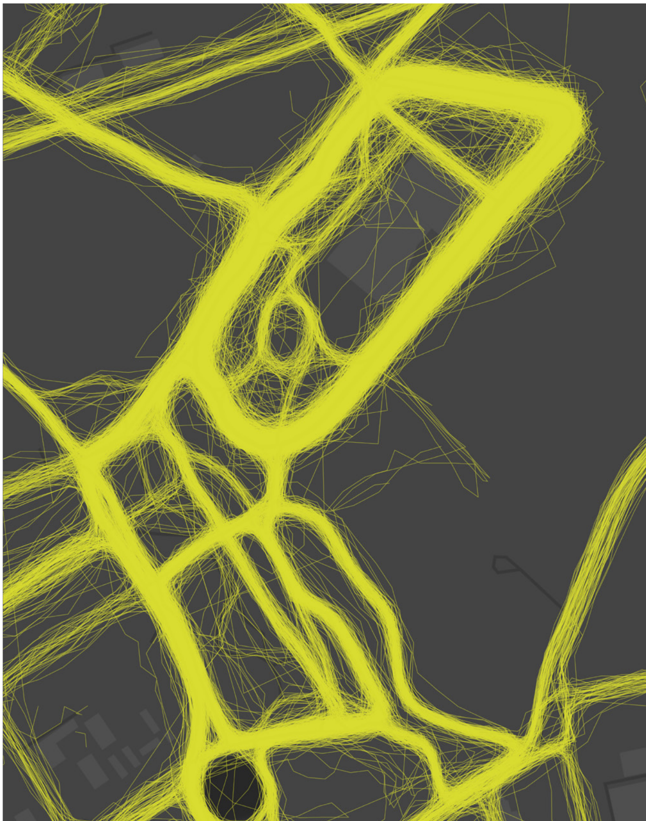

Groenvalleipark Ghent



Dommeldal Eindhoven

Karpendonkse plas Eindhoven

Liedemeesterpark Ghent



Rozenbroekenpark Ghent

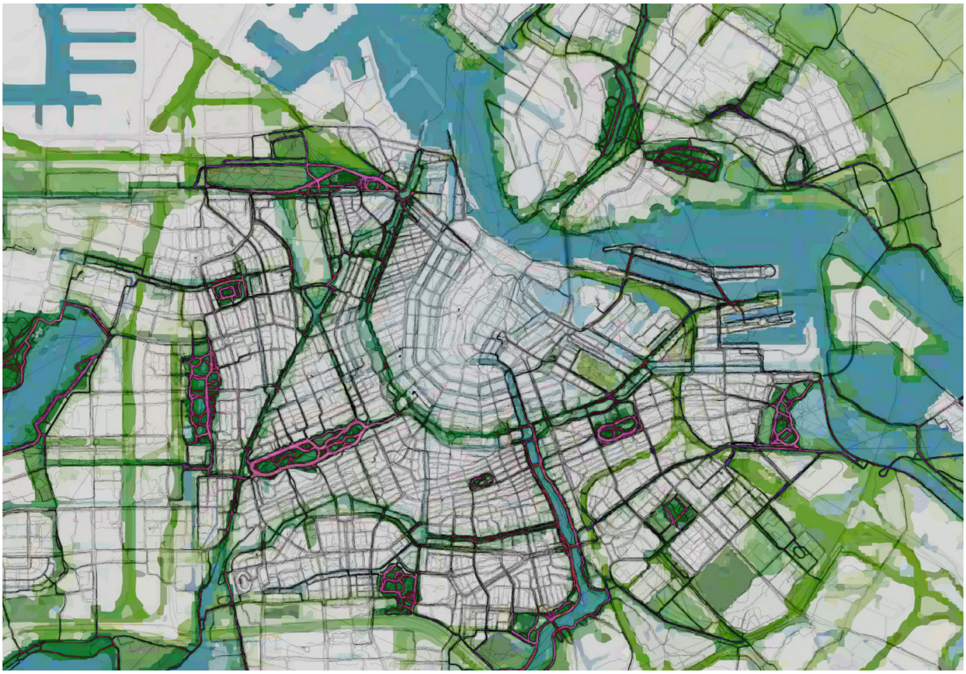


Figure 9.2: Run data merged with environmental land use data in Amsterdam.

Figure 9.3: A visualization of all GPS trails in Eindhoven, NL. Different colors represent different seasons.

Figure 9.2 shows all GPS trails of runs in the city center of Amsterdam, the Netherlands. Brighter colors and wider lines indicate more activity in those places. This revealed clear hotspots and coldspots, indicating what routes and areas were popular for running, and which were avoided.

Previous research [82,260] indicated that areas with green or water added to the attractiveness of running routes. To visualize this, we mapped runs on maps that showed land-use types. Figure 9.2 shows how popular running locations in Amsterdam map onto different environments. This clearly illustrates not only that green or water environments are popular running locations, but also shows which parks are preferred over others. By only showing or coloring runs with specific characteristics in the metadata, such as a certain distance or average speed, we sought to reveal more patterns. We also compared runs at different times to see if patterns change over time, e.g., morning vs. evening runs, weekday vs. weekend day runs or runs per season (Figure 9.3).

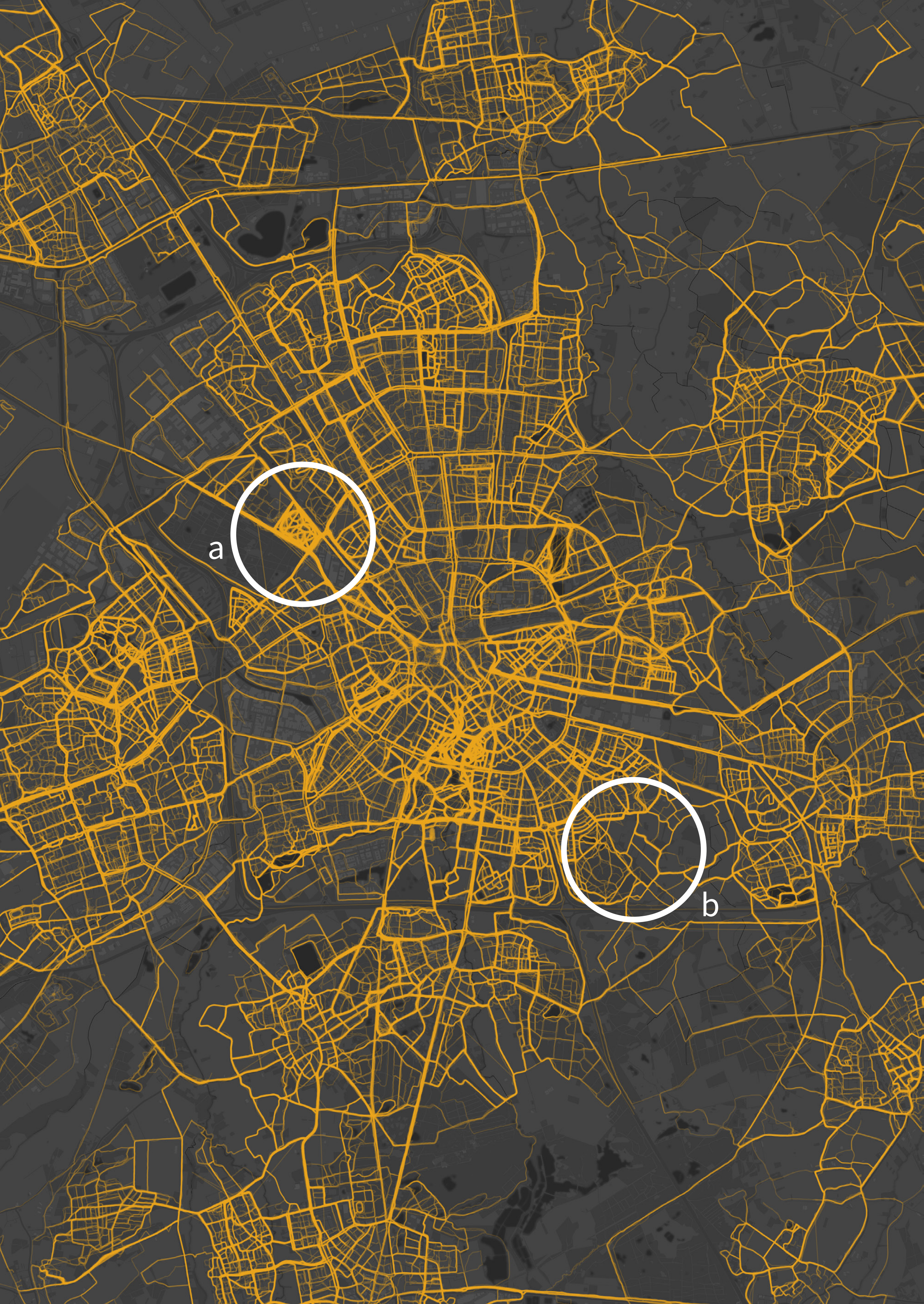
Understanding environmental qualities under different circumstances

As we explored this dataset with a focus on gaining actionable insights for the design of healthy, or more specifically 'runner-friendly' environments, our interest was mainly in environmental characteristics that can be influenced by design. In light of our explorations, we visited more and less popular areas in different cities to investigate what made them different, realizing that not only the environmental characteristics but also context has an important impact on running behavior [136]. Considering the significance of this influence when researching running behavior, we also included this in our study. Context, being a collection of circumstances, we defined by specifying several measurable aspects of it that are likely to influence running behavior.

We merged existing datasets with our running dataset, to give each run the following additional attributes; Weather data (e.g. temperature, rainfall, wind) – dataset from Weather Underground [318]; Neighborhood data (e.g. real estate value, build year) – Dutch dataset from the national bureau of statistics [54] and Light or dark – based on daily sunrise-sunset calculations.

This enabled a new set of visualizations that indicated different patterns depending on these attributes. Making separate maps for daylight and nighttime runs (Figures 9.4 and 9.5), for instance, clearly showed places without streetlights going from very popular during daytime to deserted after sunset, demonstrating the impact of public lighting (a). More remote areas, such as nature areas with few dwellings, were however also almost exclusively used during daylight hours (b), regardless of the presence of streetlights. This indicates that during the day, both urban and rural areas can be popular for running, while after nightfall the runners tend to stay in an area that is not only well lit but also sufficiently inhabited.

Applying a similar approach when merging the GPS trails with other contextual data, such as weather (rain or dry, wind conditions), comparing runs in the rain to runs when it is dry clearly shows that far fewer runs take place in the rain, but it also shows other preferred routes in both cases. Zooming in on a coastal city, the Hague, NL, we saw that alongside the beach (Figures 9.6 and 9.7), for instance, there are many runs when it is dry and almost none when it is raining (c). But at the same time, there are other areas where the weather conditions do not seem to make a difference.


a
b

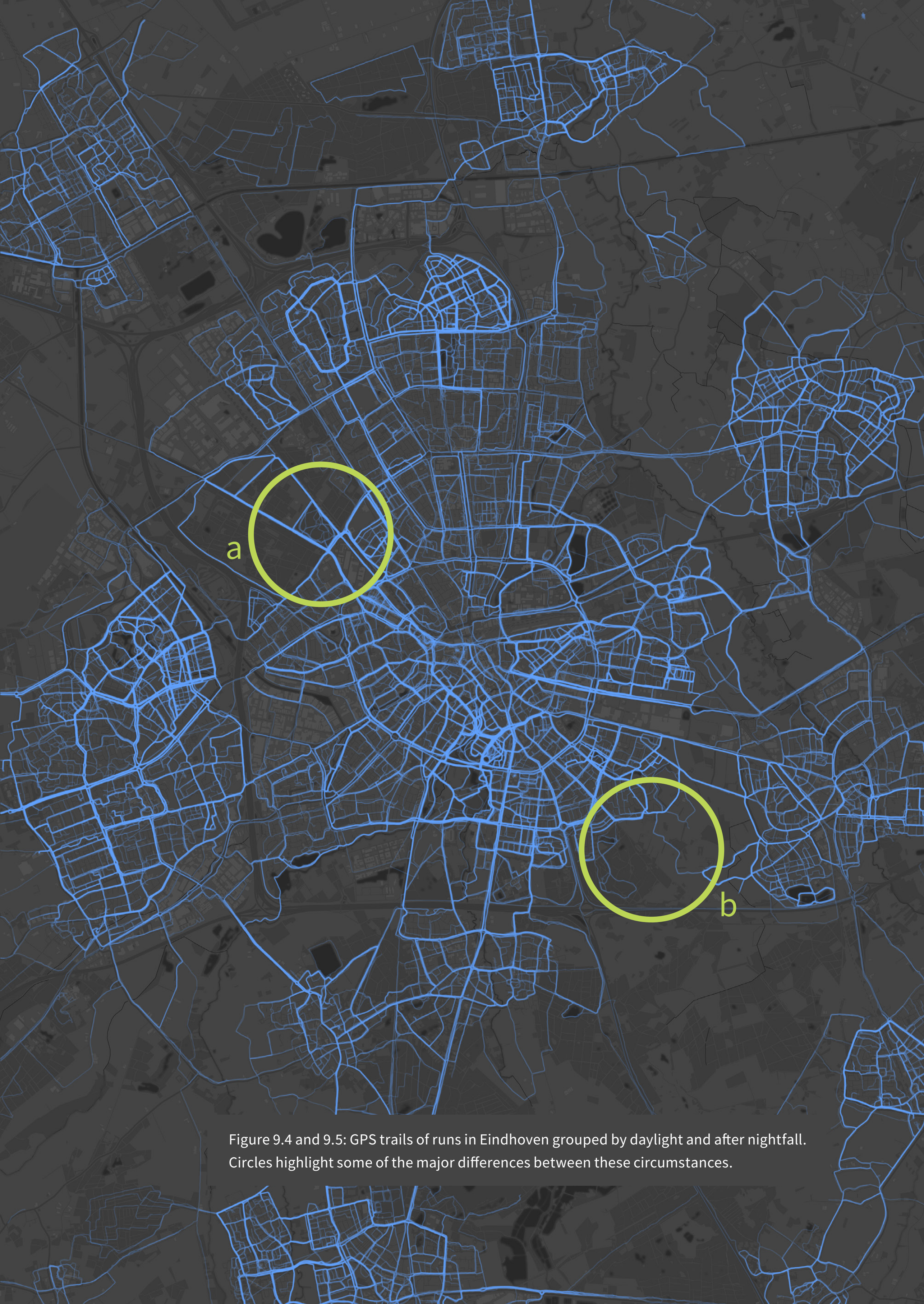


Figure 9.4 and 9.5: GPS trails of runs in Eindhoven grouped by daylight and after nightfall. Circles highlight some of the major differences between these circumstances.

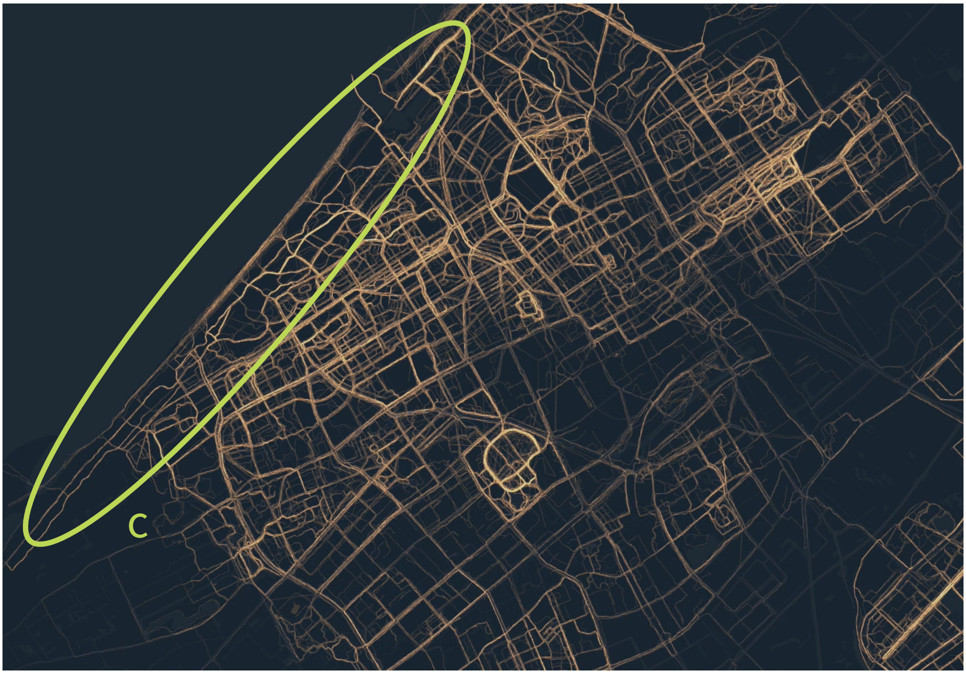


Figure 9.6: GPS trails of runs in The Hague that happened in dry weather. Shape c highlights the beach area.

Through these map-based visualizations we have explored how different environments are used for running. The introduction of more contextual data allows for easy identification of divergence between environments, based on the circumstances. For example, the preferred paths shifted when it rained or when it was dark. Our collective lens made us focus on the urban population scale, instead of on individual users. This directed our attention towards environmental characteristics that were popular for running in the general population. However, even at population level, we still see variation on preferences based on circumstances. The claim that green and blue environments are so popular among runners remains true overall (Figure 9.2), but Figure 9.4–9.7 also show that some nuance to this statement is in order. Some places indeed remain popular no matter what, but others vary greatly in popularity based on weather, (day)light or other circumstances.

9.4.4 Exploring the Individual Lens

The objective of the individual lens is to provide an emphatic focus that helps in understanding who people really are, what their needs are, in light of their running behavior. Through this lens we look in the data at what makes different people similar but also what makes them particular. Being able to find these individual uniquenesses in the data is ultimately a key enabler for further personalizing adaptive environments.

The first set of individual visualizations is derived from the available collective visualizations. Instead of overlaying the data of all users in a region, we now filter on a specific user and create separate visualizations for them. Figure 9.8 and 9.9 show the trails of two different users. We randomly

Figure 9.7: GPS trails of runs in The Hague that happened in rainy weather. Shape c highlights the beach area.

selected 250 users (with the requirement of having completed at least 5 runs), whose trails were visualized to be visually compared. The focus here was not so much on characterizing a specific user, but rather on what makes an individual singular. We searched both for uniqueness and commonalities.

These visuals gave clear insight in individual behaviors. The fact that we could compare a good amount of different users allowed us to spot first patterns. Based on their speed and distance, we often saw more experienced runners prefer straight paths without turns. Instead of creating a limited number of profiles and trying to assign these to users, we explored different personality traits and explored how we could identify these. For example, some users could be characterized by always running the same route (Figure 9.8), with only minor deviations, where others would hardly attend the same location twice to explore new terrains each time (Figure 9.9). Also differences in recreational runners and performance runners would often surface by their route choices. Interesting to note is that many of these patterns triggered more questions than they provided answers. In an ideal setup, we would be able to reach out to these people to better understand *why* they behaved in a certain way.

As these map-based visualizations had a clear focus on geospatial mapping of behavior, they missed behavior patterns that related to time. We could, for instance, not use these visualizations to understand if people only ran in nice weather or stuck to their weekly routine no matter what. To further zoom in on individual behavioral patterns, while again being able to compare and find

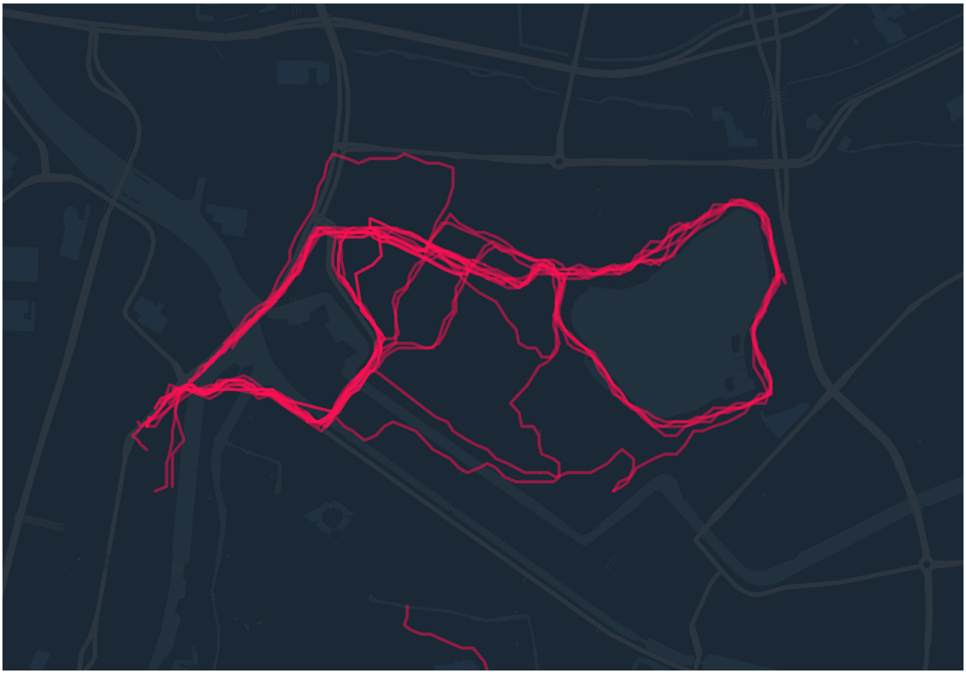


Figure 9.8: Individual GPS trails of users with mostly same route.

Figure 9.9: Individual GPS trails of users with many variations in route.

interpersonal differences, we developed an extensive visualization in which individual users would be represented. A subset of this visualization is shown in Figure 9.10.

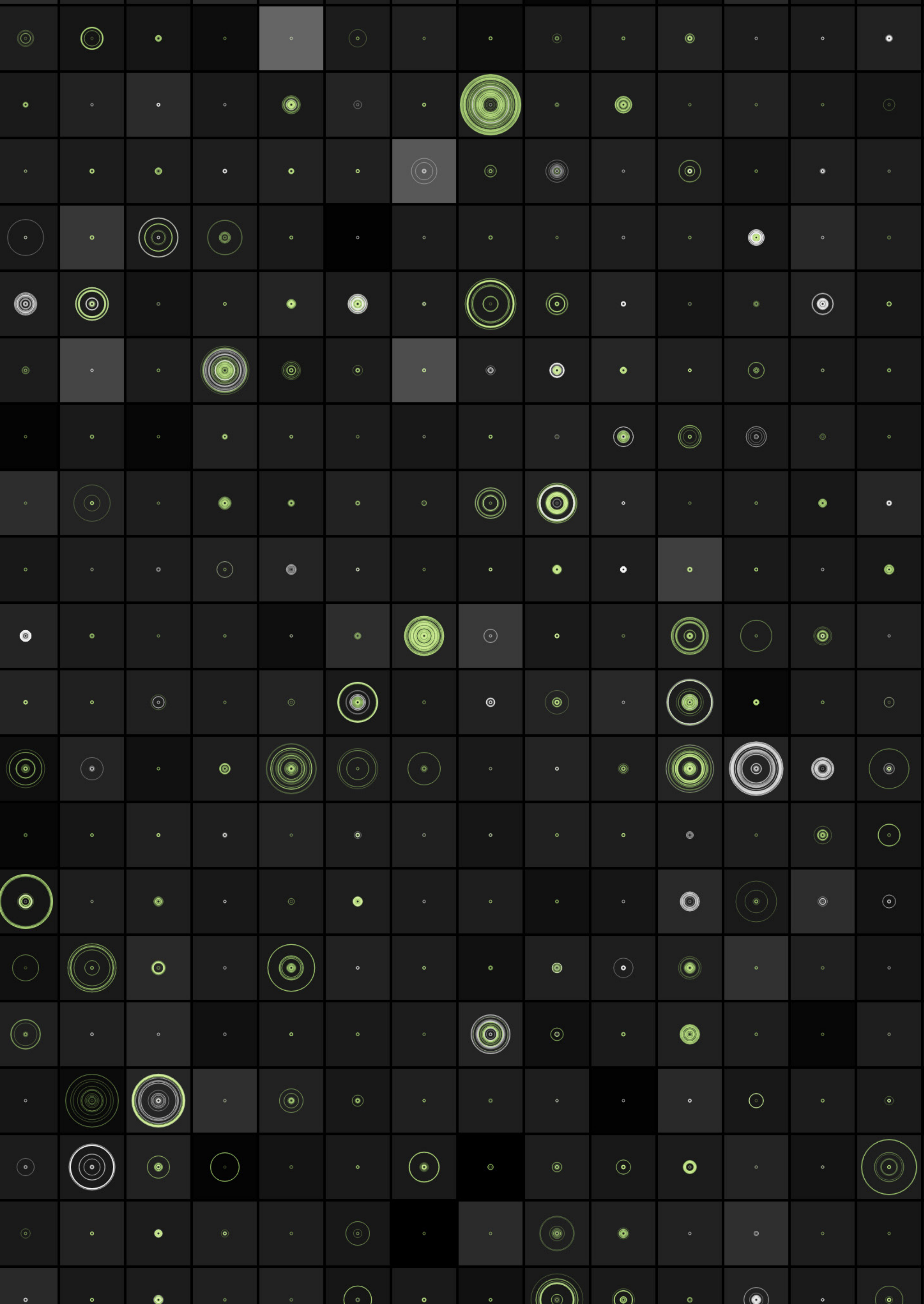
This figure shows all runs of a single user as circles in a square. Within this square the image also shows the distribution of these runs over time (from center to edge), like the annual rings of a tree, allowing us to quickly spot patterns concerning run frequency. The color of each circle indicates whether each run was part of the app training program (green) or not (white). Finally, the background color provides an indication of the average speed of all runs of that user combined (a lighter background represents higher average run speed). This visualization provides quick insights in individual user's performance and training pattern, while still providing an overview to compare many users at the same time.

The differences between squares clearly advocate how different personal routines are, yet they also show patterns in how users temporarily stop running and come back later. Rings hardly come up in isolation, showing that people who renew their running ambitions often manage to get beyond the first few runs, while being challenged to sustain that for a longer period. Their patterns are likely to give good insight in motivational strategies and can help to identify people that are motivated in similar ways. This overview illustrates that treating all these users as one 'average' person, will not do justice to this variety.

The visualization shown in Figure 9.10 successfully helped in understanding activity patterns but lacked detail on individual runs. As for the collective lens, we added more contextual data. Next to the attributes that were already added earlier (weather, neighborhood information, light or dark), we also included detailed data about the surroundings. The OpenStreetMap Overpass API [236] provided us with detailed data about the land uses along each running track (e.g. percentage of water, farmland, forest, residential area etc.).

We created a visual overview of individual user data that includes these variables, as well as time and speed progression during those runs, as can be seen in Figure 9.11. Here, time is displayed on the x-axis, which dips down to indicate the much longer timespan in-between runs, with the number of days passed shown inside those dips (i.e., bigger dip; longer time between runs). Speed is displayed on the y-axis, with the overall average speed shown in digits at the top and as a dashed line in the graph. For each run, the start time and weather information of the run is shown below, with a blue line underneath the run if it took place at night. Lastly, the colors indicate the type of environment, based on the OpenStreetMap land use data. Again, we plotted data for 250 random users with a minimum of 5 runs for visual comparison.

The patterns that start to emerge here show individual progress and environment selection combined with some context characteristics. When used for longitudinal observation, such visualizations could even help to identify influences of context or different environments on user performance, recognize characteristics of a certain type of user or predict behavior. Creating this type of visualizations also allows to quickly spot recurring or deviating patterns, without the need to know exactly what to look for beforehand. For follow-up studies these visuals can also help to quickly select 'interesting' (similar or deviant) users, either based on performance or patterns.



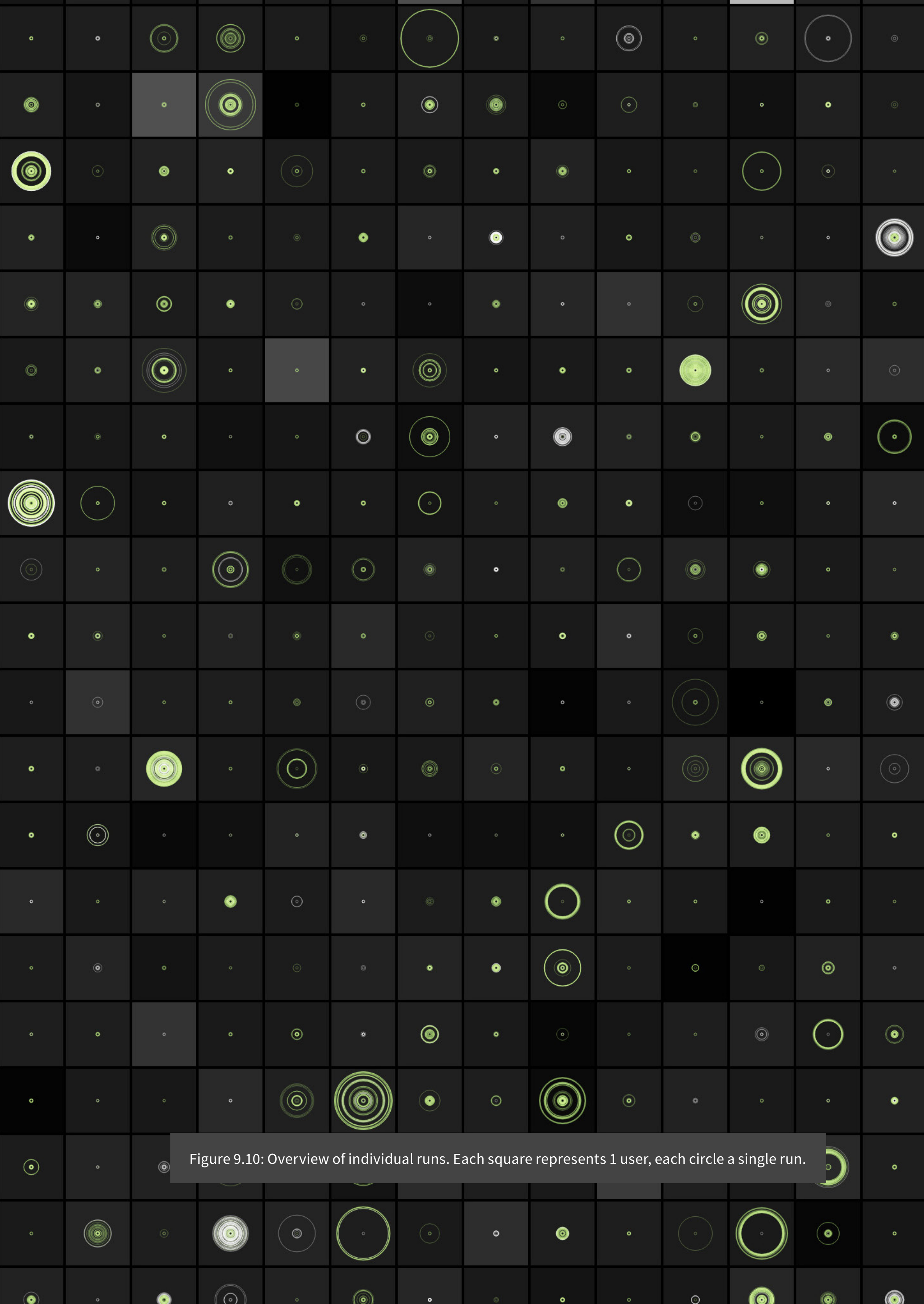


Figure 9.10: Overview of individual runs. Each square represents 1 user, each circle a single run.

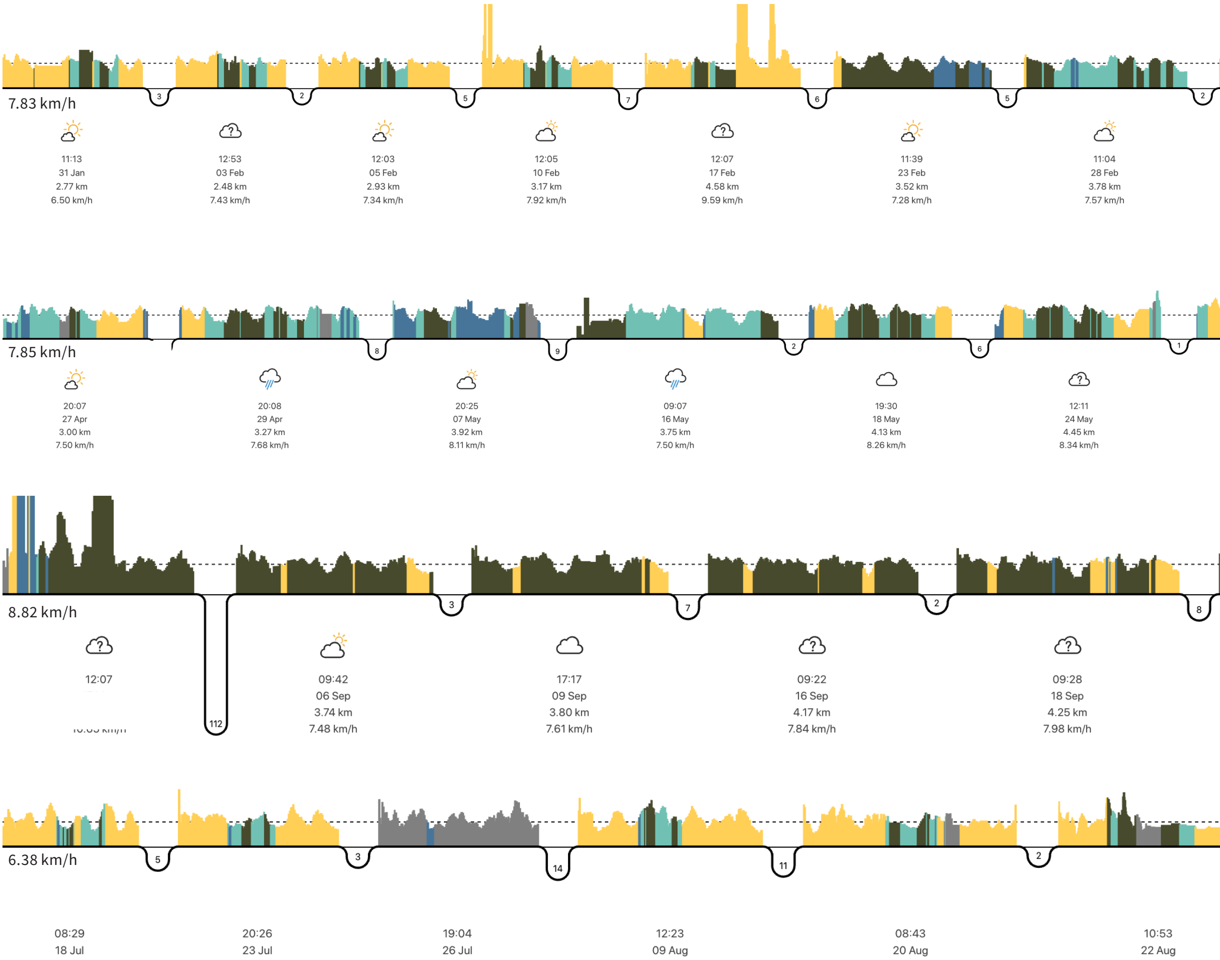
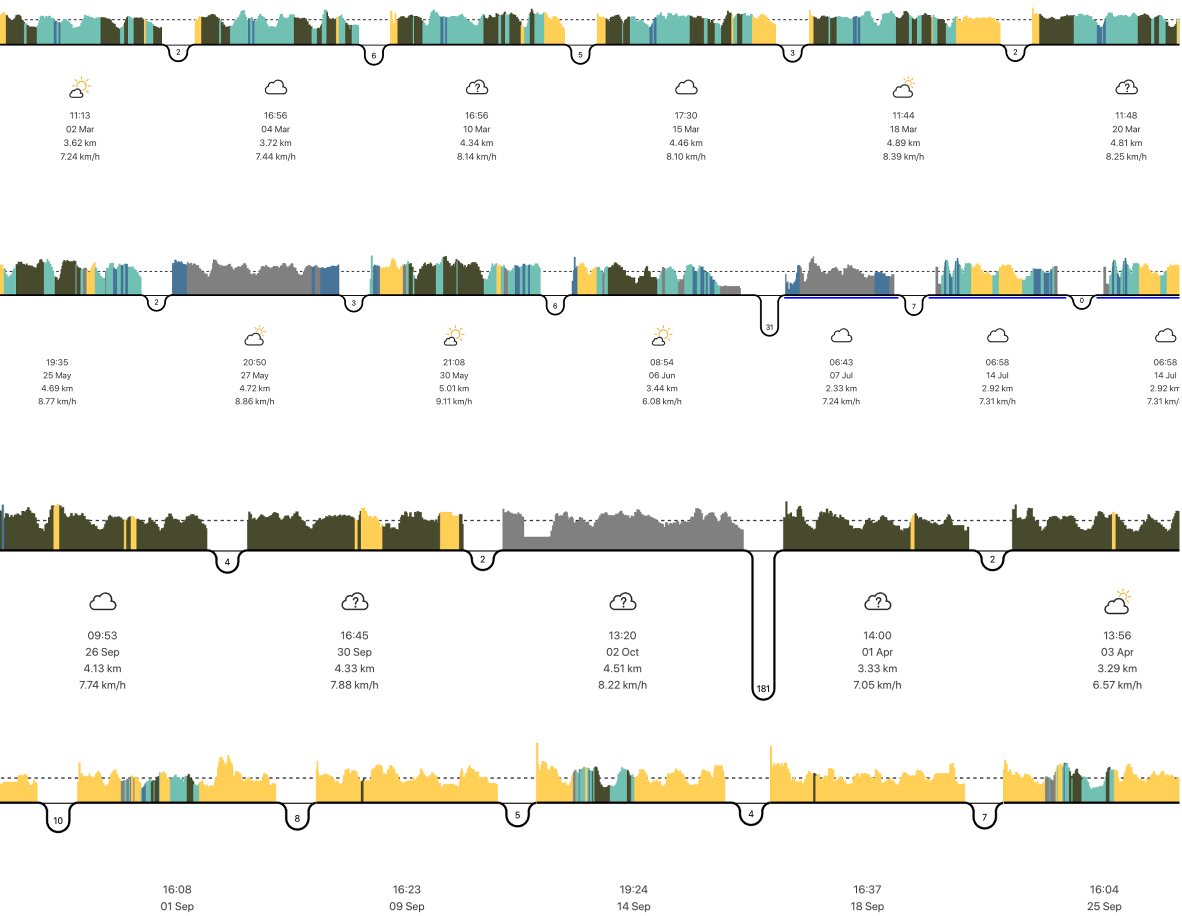


Figure 9.11: Individual data of 4 users over time; showing environment type (color), time, weather, distance and average speed (under each run), speed (height), overall average speed (below baseline and dashed horizontal line), days between runs ('dip') and if at night (blue line).

In the context of designing encouraging running environments, this detailed knowledge about individual behavior can be of great value to determine effective strategies. Especially when adopting a personalized approach through adaptable environment technologies, insights in personal routines and preferences can strongly add to their potential to encourage healthy active behavior. An interactive system could for instance guide people towards a longer or shorter route, a specific area, busy or quiet routes, or adjust light hues and soundscape, all based on personal training progress or environment preferences.

Next to learning about personal preference for running times, routes, buildup, or circumstances



and translating these into design guidelines, this approach of studying and comparing individual patterns can contribute to our cause in other ways. From a health perspective, it can for instance help to track individual progress or predict oncoming fall-out (either because of injury due to overtraining or motivation loss due to underachieving) [11,344,346]. At the same time, it can indicate effective personal training strategies [141] and help to identify unintended use of the application. From a designer's perspective, these are all points of interest. These findings provide inspiration and possible intervention points, presenting both the challenge and opportunity to intervene on a more personal scale. Based on these insights we can use technology to create digital, adaptable, or unique features that inspire users because they fit the type of person they are.

9.5 Study 2: Applying the Lenses in practice Insights from a Design Workshop

To explore the value of the introduced lenses –and data visualizations– when designing active environments, we set up a design workshop. The goal of this workshop was to test how practitioners experience using these lenses, and whether the lenses offer valuable potential to improve their process and the resulting design concepts.

9.5.1 Participants

We hosted 3 sessions with a total of 21 participants (7 women, 14 men, aged between 22 and 59 years), 7 participants per session. Participants were selected based on their experience with designing active environments; 14 design researchers and practitioners and 7 human movement scientists. All participants had professional and/or personal interest in encouraging physical activity and 8 identified as experienced runners, including 1 running coach.

9.5.2 Protocol

The workshop relied on the HME/S2R running dataset and derived data visualizations and consisted of four parts: a warm-up exercise and three rounds of analyzing and interpreting running-related data, in order to design a stimulating running environment (Figure 9.12). As a warm-up exercise, participants brainstormed the types of data they would like to collect when asked to design a 'perfect running environment' in the city.

Figure 9.12: Four parts of the workshop; warm-up, the collective lens, individual lens, combining and discussing.

Participants were then presented with data visualizations from the collective (round 1) and individual (round 2) perspectives. During both rounds, participants were asked to first describe objectively what they see in the data and then to interpret these findings (subjectively) using a provided worksheet. Based on these insights they then derived design guidelines for a fitting encouraging running environment.

For the collective lens, the same data was presented to all participants, visually showing running data of a city through heatmaps (runs colored by Day/Night, Dry/Rain, Distance, and Speed) and additional charts showing runs per user; average distance, duration, and speed per run; distribution of runs over Day/Night, months and weekdays, weather circumstances and land use (based on OpenStreetMap land use data [15]). This data was analyzed in groups of 2 or 3 participants. For the individual lens, each participant was given the data of a different user through visualizations showing a heatmap with all their running routes (Figure 9.8) and an overview of their individual combined data over time as presented in Figure 9.11.

In the last round, both perspectives were combined into final insights and implications for design. Here, we aimed to bring together the different perspectives developed earlier in the workshop and spark discussion where insights or interests do not align. To maximize diverse views in this round, participants were divided into groups of 3 or 4, representing the different groups from round 1 in each new group. Additionally, participants gained varying insights from the individual runners they analyzed in round 2.

The insights and conclusions from each round were recorded on the worksheets. At the end of the workshop participants were asked to reflect on their experience using the different –and combined– lenses and data-visualizations in this design process.

9.5.3 Results

In total, participants listed 110 types of data they would collect prior to designing a perfect running environment in the city (Table 9.1). The warm-up exercise shows a distinct preference to collect data from the collective perspective, with area information (34%) and popular running routes and times (26%) expressed as required the most by participants. Only 3 of 110 collected types of data refer to knowledge about individual users. This aligns with typical urban design practice (as described in section 9.2.1) triggered by the instructions.

Regarding the analysis and interpretation of running-related data, participants were positive about the collective data visualizations, which largely provided their most requested data from the warm-up. They found the visualizations provided a good overview and were easy, intuitive to read. These data-representations helped to *"bring out more information hidden in the data and thus design opportunities"* (P10) and *"made it easier to 'observe' actual behavior"* (P4). Looking at the design guidelines derived from the collective perspective, we see an emphasis on lighted paths, uninterrupted and connected routes, green routes, and routes providing protection or shelter (e.g., from rain or sun) (Table 9.2).

Six participants indicated that the individual lens brought in a personal level and inspired realistic

From the collective lens		
popular running routes and times		29
area information		37
environment type	10	
green	5	
water	2	
landmarks/facilities	4	
traffic and road lights	12	
pollution	2	
Surface type	1	
runner demographics		21
runner experience levels	5	
general health data –including sports participation (4)	8	
who is running?	2	
motivations and barriers		9
other qualitative data		6
weather conditions		5

From the individual lens	
user's journeys (precise descriptions of user's habits)	1
data from tracking a sample of runners over time	1
running level of user versus other users	1

Table 9.1. Desired data types to address the design challenge. Data types are grouped together when distinct subcategories could be identified. The subcategories are displayed as well.

user personas. Thirteen appreciated the timeline visualization that offered detailed information while allowing easy pattern-recognition and five noted this provided inspiration and sparked creativity. In addition to the insights into personal behavior patterns, the visualizations of the individual perspective had another interesting effect. By closely examining the data of a single user, the individual perspective strongly inspired empathy and a feeling of connectedness to that user, even though anonymous quantitative data was provided. This helped to create a more detailed persona and encouraged participants to 'fight' for their user's needs in the final round, leading to less common, more creative compromises. Several participants indicated that they enjoyed this personal aspect; the detailed information on one user made them feel connected to this person and therefore the data, which may well contribute to the renewed inspiration and creativity. "*Deep-dive into one person's story caused me to imagine motivations and project myself.*" (P13).

This increased empathy can also be seen in the design guidelines derived from the individual perspective. There's a clear overlap in main themes with those from the collective lens, with a preference for green and uninterrupted paths. However, we see an increased emphasis on creating attractive and motivating routes. The participant's desire to aid 'their' user is also clear from the phrasing of these guidelines.

Themes from the collective lens	#	Themes from the individual lens	#
Green	8	Green	10
Connected and nearby routes	6	Connected Routes	1
routes for different distance or experience level	4	routes for different distance or experience level	7
shelter/protection	8	shelter/protection	2
lighted paths	11	attractive routes –incl lighting (2)	10
motivation	8	motivation	19
uninterrupted paths -incl signage & designated routes	9	signage and designated routes	5
data collection & adaptability	4	information sharing & feedback	2
facilities	2	training frequency	6
sustainability	1		
quiet & busy routes	1		

Table 9.2. Design guideline themes derived from the collective and individual data visualizations.

The collective lens design principles were mostly stated matter-of-factly (e.g., *"Design for 'dry running' (covered but green)"* P1). The phrases for the individual lens were more focused on helping the users (e.g., *"This person often runs the same round. A predetermined route can help him to explore other routes and so increase distance."* P19). This difference is underlined by occurrence of the terms 'support', 'help', 'encourage', or 'motivate' in these guidelines; they occur in 18 of 56 guidelines of the individual lens, versus in only 5 of 55 for the collective lens.

Regarding both lenses fostered a deeper understanding of –and even connectedness to– the data and the users that would have been hard to achieve when only using one perspective. Participants appreciated the richness of data that comes from combining them as *"it combines individual stories with the generic perspective"* (P15). Combining these insights, together with the accompanying discussion, led to new insights and more creative design solutions as it "*forced us to regard different viewpoints and user desires which let us address and pinpoint new design opportunities*" (P11). An example here was the need of one runner to also look after their children, resulting in a design for a running track going around a playground. Though several participants indicated they had to look for some common ground or creative solutions to come to one design in this final stage, none of them encountered different needs or desires that were irreconcilable in one concept. This indicates that the collective and individual needs are often close enough to allow a smooth combination, and that for seemingly conflicting interests creative solutions may still offer a fitting compromise.

Participants indicated that instead of insights into 'the user' this approach gave them insights into a pallet of users, with varying perspectives and backgrounds, while still having a clear overview of how this group behaves as a whole.

Aware of this limitation of the exercise, most participants nevertheless indicated that they missed qualitative data to accompany the objective visualizations, and some wished for demographics and user context for the individual data. Several participants indicated that using an interactive interface instead of static data-visualizations could help to combine different maps for the collective lens or even the individual data compared to the entire population when combining perspectives. This will be valuable to consider in future work and when developing a method.

9.6 Discussion

In this chapter, we explored how user-generated big data can be used to design for adaptable active environments. To do this, we built on research from the fields of urban design and planning and HCI, proposing two lenses to regard this data.

Through the *collective lens*, we aim to emphasize the perspective at population level. This lens provides overview and is required to address active environment challenges at scale and in relation to the existing urban fabric in a holistic way, to make sure collective needs are served by new designs. With the *individual lens* we aim to stress the value of understanding individual needs and behavior. This lens can aid designers and planners to go beyond common denominators, to design adaptive environments that can be tailored to individual interests. We deliberately chose the terms *collective* and *individual* instead of *macro* and *micro* to address these perspectives to emphasize not only the scale, but also the human-centered focus that's at the core of our approach.

We explored the value of these lenses and how they could be utilized to aid designing running friendly environments by analyzing a large user-generated dataset through data visualizations. We tested their potential through a workshop series. Specific method development and validation of this process are outside the scope of this chapter.

We discuss our insights from using the collective and individual lens in this process and the value of these lenses for designers and toward designing for adaptable active environments.

9.6.1 The Collective Lens

In our case study, we used the collective lens to consider the data from an urban population perspective, showing overall running patterns and behavior. This perspective provided some clear commonalities that seem to apply to most runners, such as a preference for uninterrupted paths and 'green' or 'blue' areas, matching the findings of Deelen et al. [82], giving insight into favored environmental characteristics for a running environment. The data visualizations also show how such preferred running environments can change with circumstances. We could for instance distinguish different hot-and coldspots between runs in different weather types, runs during the day or after nightfall and differences in running locations over time, based on varying daytimes, weekdays, or seasons.

Instead of providing one recipe of environmental characteristics for *the* perfect running environment, this data shows that several preferences shift based on context. Designers can use this knowledge to expand the runability of a city by creating several different places, each with characteristics that are preferred during other circumstances, such as well-lit, lively places for running after dark or more sheltered routes for bad weather.

Although the maps give a clear indication of preferred environment under certain circumstances, we have to be careful when interpreting only the objective behavioral data. The reason *why* people prefer certain running routes cannot always be derived from the heatmaps. For instance, green areas are obviously popular for running, but is this indeed because there is a lot of green there, or because these areas provide running paths safe from motorized vehicles and uninterrupted by roads or traffic lights unlike anywhere else in a city? When searching for attributes of popular running environments it is important to keep this in mind as it is easy to ignore the impact of all the aspects not covered by the data.

Even though we worked with a considerable dataset, our visualizations and analysis could still not provide conclusive answers to these questions as they still provided a limited perspective. For a better understanding of experiences and the motivation behind these running patterns, future research will have to include more in-depth qualitative data, for example by surveying people in the app after their run about their running motivation and experience. However, this will need to be built into the app before data collection starts.

The size of the dataset that we used played a key role in enabling explorations through the collective lens. As it encompassed so many runs from so many people, it gave an accurate view on the popularity of different environments. A good coverage of the topic of interest is therefore an important requirement for adopting the collective lens. Next to that, adding more data to enrich the running set showed indeed to be valuable in gaining more contextualized insights [35]. It did not directly produce characteristics of popular running environments but was instrumental in understanding how environments were used differently under different circumstances. Combining these insights, the collective lens provided us with a valuable perspective on how current environments are commonly used by runners, which environments are popular under which conditions and how popular and unpopular running environments co-exist. This way, this lens provided valuable insight into commonalities within the running population that could serve as a strong foundation for designing adaptive environments.

9.6.2 The Individual Lens

Looking at the data through an individual lens, we visualized and clustered data of single users to learn more about their specific routines. Rather than only serving en masse to show averages and overall trends, we find that this information about individual behavior truly adds a new and underexplored dimension to the data. Since a population is built up of many individuals, views may diverge or even conflict on how and which environmental features influence personal exercise experiences. It is important to recognize and explore this variation in order to gain a better understanding of how adaptive environments could tailor to individual users [136]. Instead of grouping people into clusters (i.e., personas) we focused on assigning multiple possible behaviors and personality traits to each user (e.g., always sticks to their route). This reversed approach was key in honoring their uniqueness. Building data visualizations that allow for easy comparison between many individuals played an important role in this.

The individual lens provides large-scale insights in individual and personal data. While this approach is gaining traction in HCI research, this lens is not typically adopted in an urban design process. But there too, it has valuable potential. It holds possibilities to create subgroups of users based on commonalities, but more importantly it shows where and how people are exceptional, differing from the mass. These deviations and the unique, personal stories they encompass, are where both designers and health professionals can find inspiration and possible intervention points through the data.

From our workshop we learned that while the data presented in the collective lens was found valuable as it provided a comprehensive overview and general insights, it was the individual lens that inspired a true sense of connectedness with the data through the imagined other. This shows that regarding this type of personal data not only adds details, but a new depth to the data and the story it tells. It sparked empathy and creativity, and so added to the potential and scope of the considered design solutions. This is where data becomes part of the design process, when instead of imposing boundaries it enables new ways to motivate behavioral change, especially when technology allows for more and more personalization in these interventions. Therefore, the individual lens can play a key role in enabling our environments to adapt to highly personal needs and intentions, and in doing so make these environments a better fit to a larger group of people [20].

9.6.3 Toward Designing for Adaptable and Active Environments

Through the collective and the individual lens we presented a way to focus both on the urban population perspective that took into account planning and policy challenges, and the personal perspective that celebrated individual uniqueness. Both perspectives play a key role in designing for adaptable environments, covering a strong foundation based on collective values, while being able to adapt to the individual people interacting in it, under different circumstances.

Considering our aim to create stimulating running environments, considering how best to persuade people to move is essential. For effective 'mass persuasion', looking at individual users and personalizing the design is likely to be more effective than a one-size-fits-all intervention [28,85,147]. Looking back at our dataset, our findings also indicate that running behavior changes when circumstances vary. This suggests that next to advantages for persuasive qualities, an 'ideal' running environment should also be able to adapt to those circumstantial changes.

Following the current developments in human-environment interaction, 'smart' environments are increasingly equipped with the means to register these changes [109,297]. Actually enabling them to adapt to this is still less common practice, but very much within reach of current technology [266]. Since such adaptable environments would support a system that is both personalized and persuasive, they hold significantly more 'persuasive power' than systems that are only one or the other [28,147]. This adaptability is most likely to be achieved through a digital layer, offering its designers another advantage. While the physical environment is very costly and time-consuming to alter, a digital layer can be controlled and adjusted easily, even remotely. This allows not only for more interactivity and a more personalized space, but also for quick and easy design iterations, introducing the iterative design process to the domain of urban design [266].

An interesting discussion point in the creation of these adaptable environments is who or what gets preference when needs or desires from the different lenses do not align. Such differences in what constitutes the preferred environment can occur in several ways, based on simultaneous users with contrasting preferences, but also between a user's desire and 'what is good for them'. Even conflicting views on ideal behavior or use of the space between its users and designers or policy makers could lead to disagreement. Next to being 'smart' enough to recognize its different users, stakeholders, and their preference in the first place, for such cases the environment will also need clear rules on how to behave and what form to take. With possible conflict of interest between the collective and individual, here again, we see the need for consideration of data through both lenses in order to address such situations appropriately. Since varying circumstances and multiple simultaneous, possibly conflicting preferences make for a highly complex context, the quick and remote adjustment opportunities provided by a digital HEI layer could be beneficial in such an environment.

While building on HCI foundations and developments to create these adaptable environments can be a valuable asset to urban design, the urban environment is significantly different from traditional computing spaces and communities. We introduced two lenses to look at data as a way to help close this gap between disciplines. Understanding the design holistically –the small parts, the overall design, how those relate to each other and their context– requires abstract, conceptual and representational thinking [231]. Where Shneiderman's classic Visual Information-Seeking Mantra '*Overview first, zoom and filter, details on demand'* [287] clearly advocates a top-down approach, understanding and applying large amounts of data to observe existing and new behavior patterns requires and approach that is neither top-down nor bottom-up [231]. We therefore suggest switching lenses continuously throughout the design process, to acknowledge the importance of both the detailed properties of interfaces, interactions and personal experiences as well as a broad overview that pays attention to collective needs, context and long term implications [4].

A successful approach asks for a blend of many disciplines, from architecture and urban planning to sociology and psychology to computer science and engineering [243]. The development of the next generation of smart and adaptable healthy places crucially calls for a close collaboration between these disciplines. The collective and individual lenses provide a step towards that bridge, offering a user-centered approach for data and insights to be shared between disciplines.

9.6.4 Implications for Practice and Future Work

Designers have increasing access to big datasets that hold potential value for their work. This chapter provides two lenses that can help designers in regarding such data in a comprehensive way, as they include both individual and collective perspectives. With blurring boundaries between fields, this study shows the value of including interdisciplinary skills in the design team, such as adding data visualization experts.

The case study of data exploration and workshop have shown potential of using both –and combined– lenses in the design process. In future work, we will further investigate how using these lenses affects the design process and/or the derived design decisions and best practices to integrate this. This includes developing a method to help designers and other project stakeholders look at their data through both lenses. We can use this to set up a larger experiment to better understand how people perceive their value, especially in a real-life active environment design challenge. Here, we can also address several limitations of the workshop setup; adding qualitative information and offering participants (interactive) access to the raw data. Additionally, we aim to gain more insights in: a) what type of data (lens, datatype and data visualization format) is the most insightful for specific stakeholders within the design project team; b) what insights do different professionals get from looking at the same data?; c) how do they handle conflicting interests between the individual and the collective lens?

9.7 Conclusion

In this chapter, we investigated the challenge designers face as they are confronted with increasing amounts of data through a case study of creating activity-friendly environments, addressing two timely challenges. Introducing a collective and an individual lens to regard data, we demonstrated the value of both perspectives for such a design challenge. Our explorations showed how these lenses can be used to drive data visualizations that yielded significant insights on different levels, yet also gave insight into the qualities of these lenses. Illustrated through the workshop, the lenses proved to be a valuable instrument for analyzing collective needs, while also telling detailed stories about the individual. Thereby, this research provides an important step towards use of user-generated data in designing for adaptive active environments. Through this work, we additionally hope to inspire design researchers and practitioners and invite the community to reflect on the use of data in design projects and fuel the discussion about how best to adapt to this.

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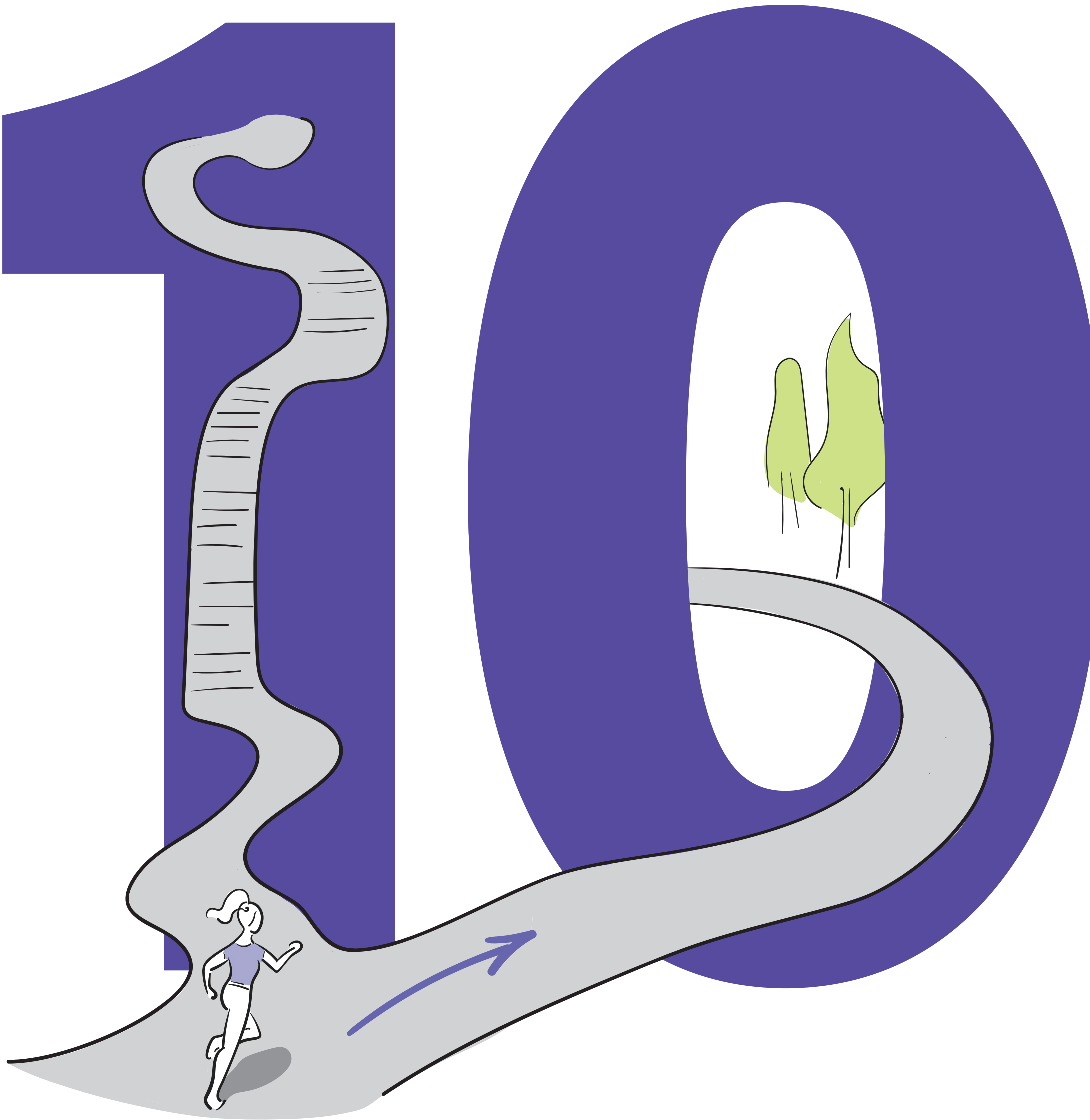
part IV

Pathfinder

Bringing together insights from all previous parts, we present Pathfinder, an extended case study that explores an alternative perspective on interActive environments, where we investigate how to address scalability challenges and further explore the use of big data to drive such solutions through AI. In this part, we explore how we can scale up interActive environments, which exist at the intersection of HCI and Urban Planning and Design, to create personalized environment experiences by smartly guiding people through existing environments. We describe how we built and deployed a high-fidelity prototype in a field study with 18 participants, showing how personalized route suggestions could affect perception of the environment. Based on these insights, we reflect on the value of integrating personalization concepts from the HCI field and the environmental focus of the Urban Design field to encourage physical activity and provide recommendations to guide the development of interActive environments.



Pathfinder

Designing a Scalable InterActive Environment Experience
through Hyper-Personalized Walking Routes

This chapter is a reproduction of the paper:

Loes van Renswouw, Sander Bogers, and Steven Vos. Pathfinder: Designing a Scalable InterActive Environment Experience through Hyper-Personalized Walking Routes. *under submission*

10.1 Introduction

There is ample research showing the negative effects of physical inactivity [33,159,334]. It is a significant societal challenge, as it increases chances of chronic diseases, such as heart disease, type 2 diabetes, stroke and obesity, and has been identified as one of the primary preventable causes of death [338]. Even though the negative effects are commonly known, many people still struggle to reach the recommended daily physical activity goals [136,159]. This problem is particularly difficult to address because it is multi-faceted and strongly rooted in many parts of our society [276], as convenience design, technological progress and optimalization have done an exceptional job in making life easier and more sedentary (e.g., cars, online shopping, remote controls, escalators or working from home). The multi-faceted character makes this a highly multidisciplinary challenge that has been addressed by many fields of research and practice. When dissecting factors that contribute to physical activity behavior, established work commonly separates between individual, social, and environmental factors [122,134,194].

So far, the HCI community has predominantly focused on *individual factors*. These encompass personal aspects that emphasize individual uniqueness, such as existing routines, individual preferences, income, or physical abilities. Building on knowledge about persuasive design and behavioral change, this field uses design strategies and digital technologies to support people in changing their behavior towards more active routines [24,53,103]. Examples of such solutions include mobile apps that help improve healthy routines [128,295,302] or motivating interactive installations [207,280]. Next to that, there is a broad body of research that addresses the relationship between individual and *social factors* [286] which describe the effects of friends, family, colleagues or communities on physical activity.

Research in this field for example shows that personal health often correlates with whether certain activities are endorsed or rejected by peers [345]. *Environmental factors* have dominantly been studied and exemplified by the urban design and -planning disciplines and describe how physical activity is influenced by built environment characteristics such as access to parks, nature, walking or biking routes, and amenities [148,166,276]. Yet, the interplay between individual and environmental factors has received less attention. This disparity has a logical cause, as changing the environment based on individual needs seems unrealistic due to resources required to make such changes on a large scale and the fact that one space is typically used by many people. The Urban Design discipline thus commonly adopts a community- and shared environment point of view rather than an individual perspective, as the scale of the challenge lends itself more for a focus on common denominators than personal idiosyncrasies.

Our research sets out to investigate how to combine individual and environmental factors in a meaningful manner, to bring together the strengths of these fields in the endeavor to stimulate physical activity. To do so, we explore and expand on the concept of interActive Environments [266]; interactive spaces that encourage physically active behaviors. With their persuasive interactive technology embedded in the public outdoor space, these interActive Environments can provide a tailored user experience in the urban space. Such smart adaptability could offer a wealth of new opportunities as it allows a highly personal approach where the system can adapt to the needs and preferences of different users, even as these vary over time. This flexibility enables the optimization of persuasive strategies and an improved experience by tailoring its behavior to individual situations.

In this chapter, we investigate an alternative perspective on interActive Environments that could have impact beyond a single location. We do so by moving the focus from making changes to the physical characteristics of the environment to allow it to adapt, to using digital technologies that can change people's perception of their urban environment. We adopt a research-through-design approach [357,358] as we design and develop a solution that can create highly personalized environment suggestions based on user preferences. In doing so, this chapter contains the following 4 contributions: (1) We present results from an explorative questionnaire that investigates the role environments play in the individual's activity experience and which challenges people face when finding good environments for their physical activity. (2) Based on those insights, we present a novel design concept that envisions the use of an intelligent routing app to combine individual preferences with environmental characteristics to create a hyper-personalized environment. We present a fully functional prototype of this concept, that makes hyper-personalized routes generated by an advanced pathfinding algorithm, accessible in our easy-to-use Pathfinder app. (3) We present insights from a qualitative and data-equipped in-the-field study over 3 weeks. (4) Finally, we discuss how this exploration contributes to current challenges in the domain of interActive environments, by articulating how digital representations of the environments can be used as building blocks for interActive experiences that can be scaled beyond single locations.

10.2 Related Work

The HCI and Urban Design fields have extensively investigated factors and strategies that can contribute to more physical activity [67,146,291]. In this section, we outline research that gives insight into design strategies that can contribute to encouraging more physical activity. We focus on the influential potential of the environment, the opportunities provided by personalized technology, and how improving the experience of the activity can lead to more active behavior.

10.2.1 The Influential Potential of the Environment

People's daily urban systems (the environment in which they live their lives) strongly influence how their routines are shaped. The design of urban environments can therefore be an important tool in stimulating more active behavior [167,275,327]. Such designs can be inviting through aesthetic appeal, but also influence behavior by non-intrusively guiding behavior, known as nudging [104,310], seducing (i.e., offering attractive features that require some form of exercise), or more obtrusively by offering limited options (i.e., only offering stairs to reach higher levels) [263]. This makes active environment design a popular endeavor in both Urban Design practice and research [136,148] and a powerful tool to address population-wide physical inactivity.

As many people share the same public space, especially in an urban area, the design of one environment impacts the routines of many people. Changes are difficult and costly to implement, so once realized, a design should serve its purpose for a considerable amount of time. Focusing efforts on these places is also valuable from an inclusivity point of view, as one design can potentially influence a large and diverse group of people, including those who might not be able to get access otherwise (e.g., for financial reasons) and even the hard-to-reach group that is not consciously trying to change their inactive routines [266]. At the same time, this requires treating the collective of users as one, focusing on averages and generic benefits for the group.

10.2.2 Personalized Technology

Influencing a large, heterogeneous audience effectively is difficult when using a one-size-fits-all approach [28]. Persuasion shows to be most effective when the right message is delivered at the right time and in the right way [147], which can vary between individuals in the target audience. Doing this based on personal user data can therefore increase the impact of persuasive technologies that are used to encourage behavior change [28,147,235].

Advancing technology brings an increased potential by enabling a shift from one-size-fits-all solutions to persuasions that can adapt to specific contexts or users [28,50]. The effectiveness of personalization to enhance persuasive power can be seen in the popularity of this strategy in smartphone applications aiming to improve physical activity, health and wellbeing [199,239]

Promising developments for our challenge can also be seen in the shift from Human-Computer Interaction towards Human-Environment Interaction (HEI) [297,306] or Human-Building Interaction [6], where HCI technology is increasingly embedded in the environment. As this trend allows more omnipresent and less noticeable applications, it enables the embedding of smart, interactive, and/or persuasive technology unobtrusively in people's living environments. An example is the shape-changing door by Economidou and Hengeveld (2021), that reveals or conceals its handle based on occupants' desires [88]. Such opportunities provided by HEI bring the potential to encourage and support physical activity through more personalized environments.

Next to personalization, there are other commonly known motivational strategies that can be adopted. For example, triggering curiosity and providing autonomy have proven to be effective methods in different cases [28,103,284]. In turn, stimulating exploration and discovery have been shown to boost the curiosity process [314] and evoke positive emotions [353].

10.2.3 Improving Physical Activity Experiences

The enjoyable aspects of exercising are a key part of what draws people to physical activity [136]. Greater enjoyment and satisfaction relate to a greater intent to repeat the activity [213,313]. To encourage active routines, moving the focus from health benefits and increased performance towards improving experience is therefore an effective strategy [213]. In line with what is known about the influential impact of the environment on behavior, the environment plays a big role in the extent of exercise enjoyment. This is demonstrated by Coon et al. (2011), who reviewed 11 studies to compare the impact on the well-being of physical activity in natural environments to physical activity indoors [313]. A study by Calogiuri & Elliott (2017) rates 'experiencing nature' as the second most popular motive to engage in physical activity, outranked only by convenience arguments [47].

At the same time, convenience has become a popular motive for the type and time of physical activity [47,97]. Being able to go 'anywhere, anytime' is one of the reasons running and walking are such popular forms of physical activity [41,47]. This trend is directly related to the fact that 'lack of time' is one of the main perceived barriers to physical activity [145,307]. Lowering barriers to physical activity can contribute to an improved experience and so help to turn exercise from an additional 'must' on people's lengthy to-do lists to a 'may' they want to integrate into their day.

Combining the advantages of convenience with the positive impact of a suitable, stimulating environment is challenging. People first need to find such an environment, often commute there, and then plan a fitting route through it. This all takes time. Also, what constitutes a 'stimulating environment' may vary greatly per person, as well as over time or under other circumstances such as varying weather conditions [136,276]. This limits the suitability of solutions that offer route suggestions based on crowdsourcing, such as Strava [302] and Komoot [161], as these are once again based on other and/or average user preferences and circumstances [73,100]. Personalization and adaptability of the environment can therefore play an important role in further increasing the stimulating effect of the environment.

10.2.4 InterActive Environments

Combining the influential power of the environment with tailored, adaptable HCI solutions, the concept of interActive Environments describes spaces with embedded smart, tailored and adaptable technology that encourage physical activity of their users [266]. We see potential in this direction, as first design cases [261,264,265] show how interactive and persuasive technology can help in embedding physical activity experiences in the built environment. This approach also offers the inclusive advantages of intervening in the urban public space.

Currently, examples of interActive Environments are often limited to local experiments of how areas can be enriched with interactive technology to stimulate physical activity, such as The Pearl Divers by Daily tous les jours [75] or the Piano Staircase by the FunTheory [311]. Although these solutions have proven to be effective on a small-scale [245], they are hardly implemented on a large scale because these projects require a significant amount of time, resources, and local politics to deploy.

One of the major challenges for interActive Environments is this scalability. Multiple experiments and case studies show the potential of these solutions on a small scale [245,266]. However, sustaining such installations for a long time and scaling up to expand range and increase impact remains a challenge, as this is typically a resource-heavy, costly and time-consuming endeavor [266]. It requires physical alterations to the existing environment, needs maintenance, and the interactions often bring a modern or even futuristic feel to the area. This makes the approach less suitable, feasible, or desirable for certain places, such as historic city centers.

10.3 Research Objective

Building on the introduced research from HCI and Urban Design fields, we investigate how we can create an interActive Environment experience that combines individual or personal preferences with environmental characteristics, to create a stimulating physical activity experience. In this study, we pay special attention to the challenge that interActive Environments are complicated to scale up.

In our early brainstorms, we got fascinated by the Harry Potter staircase [270,328] as it offers an interesting surreal perspective on a large interactive environment. The individual stair segments do not change their form but reconfigure themselves all the time creating completely different journeys for their visitors. What if instead of changing the properties of the environment (i.e., the properties of the stair segments), we could digitally reconfigure their environment in such a way that people would experience that environment in a completely different manner (i.e., changing the orchestration of stair segments)?

By building on this metaphor, we set out to investigate an alternative perspective on interActive environments, where it is not the environment itself that changes but a person's journey through –and therefore, their experience of– that environment. This way, we aim to address scalability issues of the interActive environments concept while still using the qualities of the built environment to create highly personalized experiences.

10.4 Exploratory Questionnaire

To gain a more detailed understanding of how personal environment preferences differ, we ran an exploratory questionnaire study with 22 participants (9 male, 13 female) between 25 and 70 years old, all residing in Western Europe. Participants were recruited through an invitation call on the intranet of a higher education facility, with some additional convenience- and snowball sampling. In the qualitative questionnaire, participants were asked about their current walking (or running) behavior, their ideal walking environments, and the challenges they currently face when planning a walking route. The survey results served to identify design opportunities for our next step and was not intended as an extensive and conclusive evaluation of current practices. All studies presented in this chapter were approved by the University Ethics Board.

10.4.1 Ideal Walking Environments

When asked about their ideal walking environment, natural environments were mentioned by all participants. Forest, fields, water, and parks were often mentioned, but also more generic terms such as 'green' or 'natural'. In combination with 'green', 11 participants described their preference for a peaceful, calm, or quiet environment. At the same time, 5 participants mentioned a preference for alternation and variation; between quiet and natural, and busy and urban; or as they enjoy exploring new routes and places. 3 participants mentioned climbing, adventure, and a route that provides a sense of accomplishment. Even though commonalities like these were there across people, it was also clear that participants often have quite personal perspectives and preferences. They for instance indicated preferences for a fun area for kids (P8, P16), roads that are unpaved (P2), suitable for a stroller (P16), free of mud (P17) or allow dogs to walk off the leash (P22).

These preferences were often further articulated in later questions, stressing how their environmental preferences were strongly context-dependent. Most participants indicate the weather has a large impact on their walking habits (n=14), but also their available time and stress levels (n=9), other people (n=7), darkness (n=5) and familiarity of the environment (n=2) are named as main influencers.

> *"When it's stormy weather I take a shorter walk, and closer to home. After dark I don't really go to nature but stay in urban areas. When traveling abroad, I keep to more populated areas in the evening." (P10)*

When aiming to design an 'ideal walking environment', it should therefore not only adapt to personal preferences but also have awareness of the current context.

10.4.2 Current Route Mapping Practices

Participants reported on a variety of challenges when asked about how they currently went about finding a good activity route. For familiar environments, they determine their walking routes mostly based on the type of environment they want to walk in (n=12) or the amount of time they have available (n=6). Some name other factors such as a destination (n=2) or suitability for their pets (n=3). Several participants also mention they either 'just go' (n=8) or use 'typical routes' for spontaneous walks (n=5) to avoid spending much time or thought on route determination altogether.

> *"I just choose paths on the go, no real plan before other than the direction or 'theme'; woods, fields, urban etc." (P20)*

> *"For my morning walk I often plan a route by walking towards something I pick randomly (a building, company, store) in a particular order. In the case of a longer walk I often just walk 'randomly' until I don't want to walk anymore and from there I simply just walk back." (P9)*

When asked about frustrations related to walking in familiar places, lack of variety is cited most (n=8). Participants also mentioned busy (n=4) or blocked roads (n=2), time related issues (n=3) or dangers (n=2).

> *"Sometimes I want to discover a new area, but I always think about the same place... it is often the most crowded one (I live in a city). If I want to see beautiful things or Nature I always go to the same areas." (P12)*

In less familiar places, most of our respondents use digital means to find suitable routes. Many make use of digital maps, like Google Maps (n=13) or other apps (n=3) to manually map out their activities. Others look for existing routes on local information websites or maps (n=6) or follow signage on site (n=4). 8 participants indicated they liked to 'randomly go and see', but often still used a digital solution in case they got lost (n=5). In short, this means that for most of our participants a walk in an unfamiliar environment requires (online) research and preparation, which are likely to become barriers when time or enthusiasm are limited.

> *"We either look at public information (guides or websites) if we want a pre-planned walk– or simply use Google Maps, and check on the go if we are on a more spontaneous walk" (P16)*

> *"I check online what is more interesting to see if it is a trip, because I would be interested in discovering new places. But if I am only walking for the sake of walking, I would go randomly towards a direction that seems more appealing and safer to me." (P11)*

While finding the way (back) in a familiar environment is typically not much of an issue, participants indicate several grievances with wayfinding in an unfamiliar place. These include that it is time-consuming to find good routes, outdated route information, routes being longer or shorter than expected, disappointing scenery, getting lost, and needing an(other) app to find their way.

> *"Usually, I don't have the time to discover when I'm in a new place. Hence, I probably miss out on the best routes." (P4)*

> *"If I am checking online what places I should visit, it is frustrating that the info is not updated [...] If I am going randomly, the fact that I unexpectedly find a short route frustrates me a lot, because it will make me go backwards." (P11)*

10.4.3 Identifying Design Opportunities

This exploratory research gave first insight in personal preferences regarding environments for walking activities. From these findings we distill the following four design opportunities that serve as a starting point for our design step.

- Environment preferences for walking routes are highly individual. Although there are common denominators, there are always idiosyncrasies.
- Environment preferences are temporal and context dependent.
- With limited time being an important perceived barrier, people are looking for an easy and quick way to find a route that fits their needs. The time investment required to find a nice route is considered a major barrier.
- People are looking for an integrated solution that allows them to find routes and navigate them easily.

10.5 Pathfinder: A Hyper-Personalized, Environment-Centered Route Generator

There is already an abundance of apps that help in finding activity routes, but to our knowledge, none focus primarily on a personalized environmental experience. Popular apps like Strava [302] and Runkeeper [101] use the power of the community to create and share routes. This allows users to follow routes in areas that are better known by others, likely resulting in better experiences. The downside is that these routes are not personal or context dependent. Users first must find their way to a starting point, the preferences of that other user might have been different from their own (e.g., the other user being more okay with soft surfaces), and the route might have been followed under different conditions (e.g., when it was summer instead of winter). Navigation apps, like Google Maps [119] or Mapbox [195] could potentially play a role here too. Yet, the presets these apps contain are often limited to the fastest route or shortest route, not, for example, the most idyllic route. They also primarily focus on navigating from A to B and not on creating circular recreational laps. With Pathfinder we set out to create a novel personalized routing system that takes individual environment preferences into account. The system consists of two major components. The first one is the intelligent routing engine itself. The second is a smartphone application that allows the user to input preferences, review, and follow routes suggested by the routing engine.

10.5.1 The Intelligent Routing Engine

The job of the intelligent routine engine is to find the perfect activity route based on the user's preferences. To do that, the engine needs to have a detailed understanding of the user's environment. The more granular this data, the better it can tailor to specific needs. Ideally, we combine high quality data from different global and local sources to reflect many topics that are of interest to the user. In reality, it is safe to assume we can only get access to a limited collection of attributes and have to work with that. For this experiment, we start by using data from the OpenStreetMap platform [237] as the primary data source. OpenStreetMap is a crowdsourced, open license equivalent of Google Maps and contains a wealth of environmental data that can be accessed through their Overpass API [236]. These include road types, land use types, points of interest, waterways, curated routes and more. This data is globally available, although of higher quality in some areas than others, allowing us to develop this solution on the scale we are aiming for.

The routing algorithm is built to run in two stages:

The first stage analyzes the local environment based on the user's location, processes the data, and returns the available environments to the user. To do this, it first collects the full road network graph of the area, together with all the available segment properties. This comprises the type of road (e.g., highway, footway, bicycle path), but also attributes such as surface type, maximum speed and whether it is accessible by foot. Next, it downloads environmental data. This entails a detailed description of land uses, buildings, and waterways in the region. The environment data is mapped to the road segments. As a result, each road segment contains a detailed description of its environmental properties, e.g., if there are trees, grass, water, walkways, streetlights, etc. This first stage saves that graph (see Figure 10.1), to be used in stage 2, and returns all available options to the user to ask for preferences (see app description).

The second stage uses detailed user preferences to find the optimal route. First, it uses the user preferences to score each route segment. After that, it runs a wayfinding algorithm that attempts to collect as many points as possible, within the specified range. Although this approach is conceptually straightforward, it is technically a highly complicated one as the circularity of the route makes this a computationally challenging problem (i.e., NP-hard). The details of technical implementation are outside the scope of this paper, but it is good to note that several techniques have been applied to solve specific issues that could have major UX implications, as these determine what routes are generated. For example, we choose to implement the wayfinding algorithm in such a way that it would first try and find a rough path and in a second iteration it would concurrently fill in the details (see Figure 10.2). This prevents that, in case a user shares a preference for walking in parks, the greedy algorithm simply finds the most nearby tiny park and circles there for 10 km. Also, we did not allow the algorithm to use the same road twice, to stimulate variety. Once completed, the intelligent routing engine returns a maximum of three suggested routes to the user. These three options are constructed from high level routes that were already quite different in the first pass, to prevent highly similar options.

10.5.2 The Pathfinder Mobile App

The app should be simple and quick to use, to make sure we do not introduce any barriers. The flow is described below.

The illustrations in the app are more than window dressing. They are generated artworks that accurately reflect different environment types along the route. In earlier iterations, we only used map visualizations, but people commented that map overviews were quite meaningless in environments that were unfamiliar to them. We therefore introduced a simple visual representation of the route, that should give a good first understanding of what that route has to offer. Figure 10.3 shows an example of a translation of a route definition to a route artwork.

10.6 Field Study

The field study investigates how the Pathfinder concept delivers on its ambition of creating more personalized and enjoyable walking environments based on individual user preferences. To do so, we developed a fully functional prototype, Pathfinder. In this prototype, the intelligent routine engine was running on a backend server that would compute routes directly upon requests from the app. The app prototype was developed in React Native, made available for both Android and IOS devices and distributed through public stores. All activities, user preferences, and user feedback were stored on the server so they could easily be remotely reviewed in real-time by the research team. The app was also equipped with Firebase Analytics so we could track engagement, retention, and basic funnels to spot errors and usability issues.

We recruited 18 participants for the study. Participants were aged between 25 and 70 years old, enjoyed walking as a recreational activity, and had experience in using mobile apps. Participants were given basic instructions for downloading and using the app. They were asked to try and complete 4 walks in a 3-week time span. Preferably 2 of these walks should happen in familiar surroundings and 2 in unfamiliar surroundings. Participants could decide when and how far they wanted to go and received no instructions for setting environmental preferences.

After each activity, participants were asked to fill in a short post-activity online questionnaire. This questionnaire contained questions about how they experienced the environment that was created for them, including what they liked and did not like about it, how it compared to previous walks,

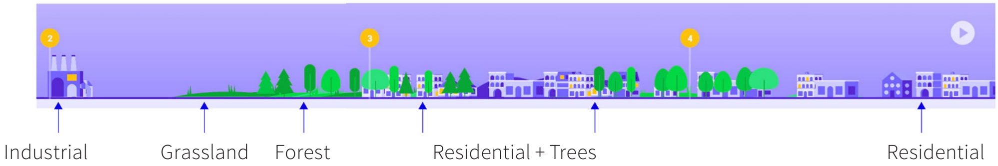


Figure 10.1: Dynamically generated artworks based on the route details.segment. (e.g., green for trees, purple for industry, yellow for grass)

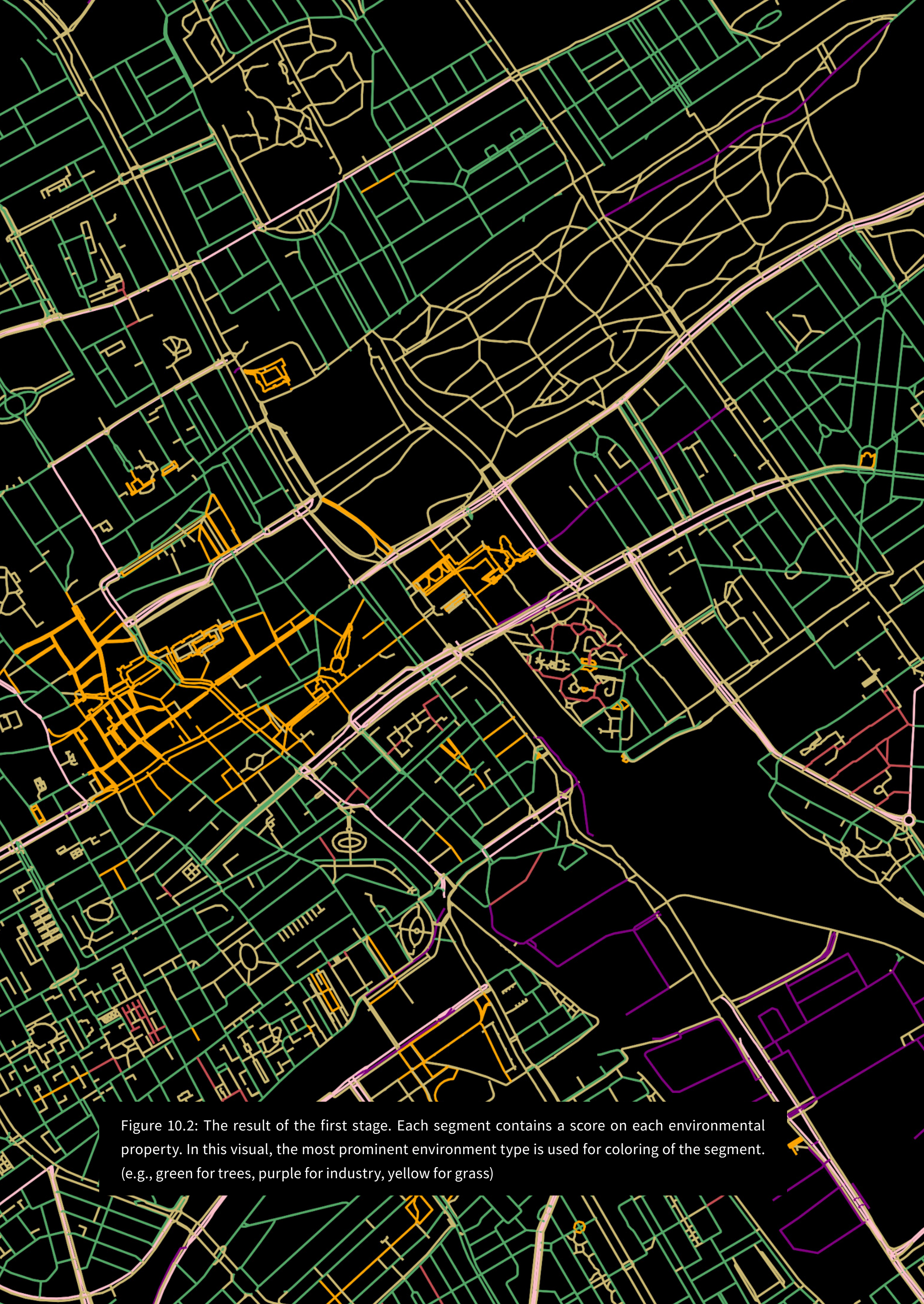
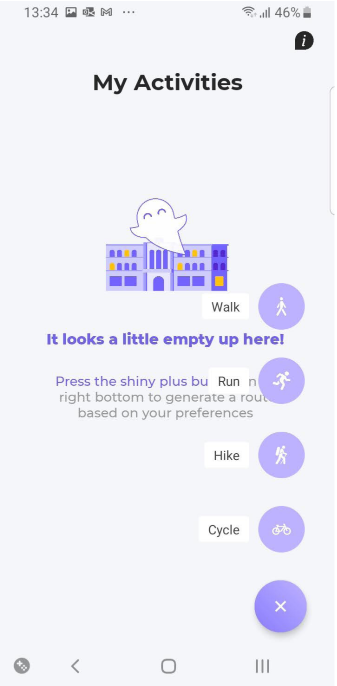
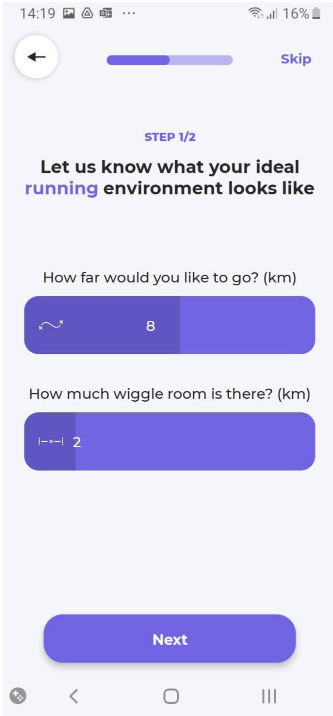


Figure 10.2: The result of the first stage. Each segment contains a score on each environmental property. In this visual, the most prominent environment type is used for coloring of the segment. (e.g., green for trees, purple for industry, yellow for grass)

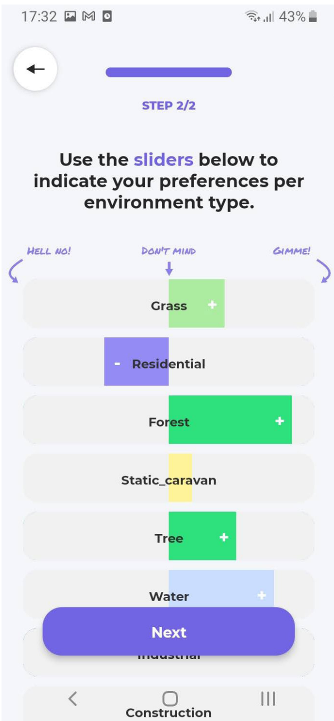
Figure 10.3: The result of the second stage. The colors on the road network contain the score of each route segment, based on the user’s preferences. The red line shows a suggested route. The dots were used to determine a rough path on the first pass.



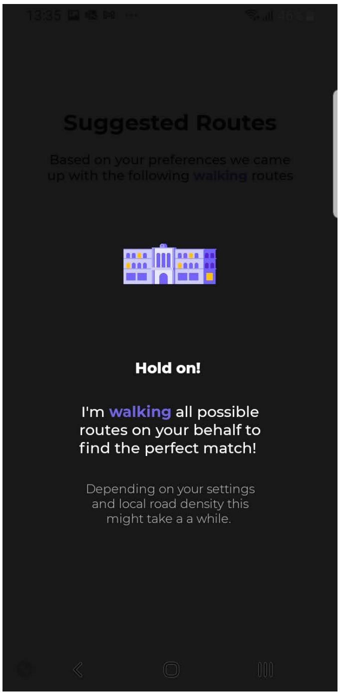
Users can start a new activity by choosing their activity type. This provides a first filter on the route network. For now, only walking is supported.



Next, the user selects how far to go in km. If the range of their preferences is larger, they can agree to suggestions that deviate a bit from that distance.

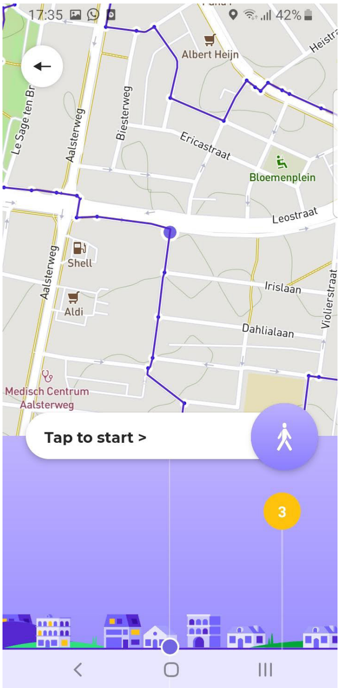


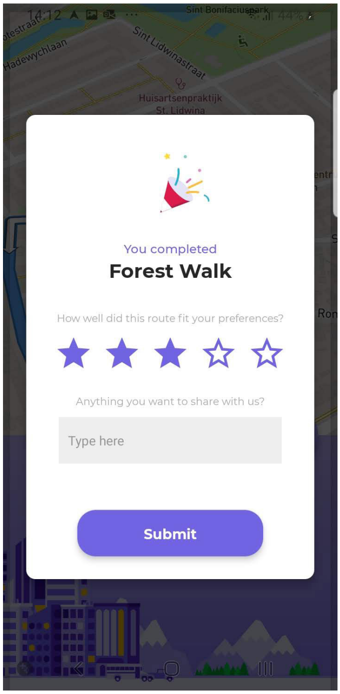
The routing engine scans the area and returns the options. Sliders are used to indicate positive and negative preferences. Continuous values give users control.



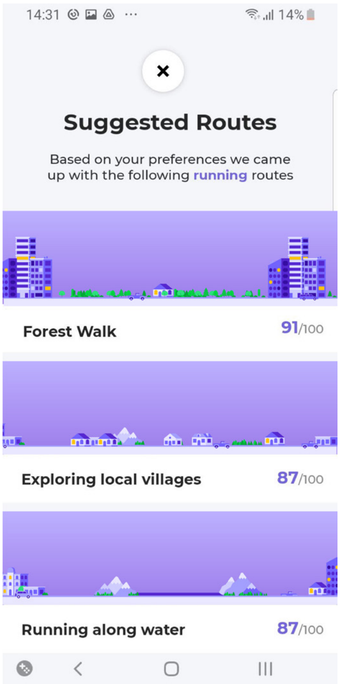
The intelligent routing engine explores best options. In the prototype, this could take a few minutes.

Users can open suggested routes. After choosing one, they can switch to navigation mode to receive turn-by-turn instructions.

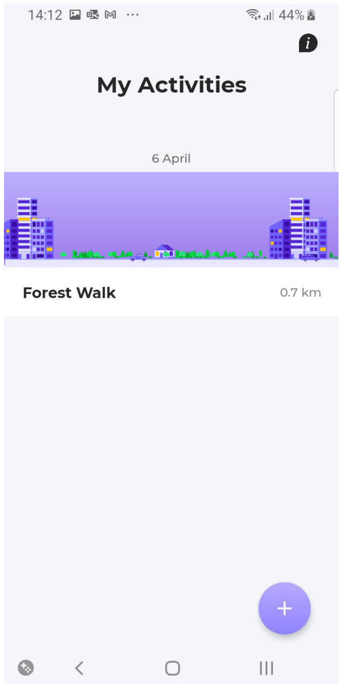




When the route is finished, either by reaching the end point or manually stopping it, a feedback modal asks for a route name and feedback.



The suggested routes are presented to the user in a simple overview.



The route is saved and added to the user's wall. This gives a nice reward for the achievement and allows users to redo routes from the past.

and whether it matched their expectations. A few questions were included about their experience using the app. At the end of the three-week study, participants received a final questionnaire that contained a mix of open and closed (Likert scale) questions. For all closed questions, an open follow-up question invited participants to elaborate on their answer. This survey contained questions about their general impressions of Pathfinder –how they experienced using it, what they were surprised by and what could be improved– and its impact on their perception of their surroundings and the walking experience. The results of these questionnaires were analyzed in combination with the data that was logged by the app (i.e., preferences, route suggestions, the actual route followed, and route feedback).

10.6.1 Results

In total, 18 participants (7 male and 11 female) completed at least one activity and filled out the accompanying post-activity questionnaire. Together, the participants completed 50 activities, 34 in familiar environments and 16 in unfamiliar ones. The experiences participants shared were mixed, ranging from being positively surprised and amazed at moments when Pathfinder suggested a great route based on their preferences, to being disappointed and annoyed by a bad route or functional app issues. In general, most people were excited about the value Pathfinder could bring them, although the current prototype did not always deliver on that promise. Participants described Pathfinder as an easy-to-use app that helps you discover new walking routes without much effort and an app that can make your walks more enjoyable based on your walking preferences.

Considering our research objectives, we discuss our findings in three categories. First, we focus on the core of our proposition as we evaluate how participants experienced the suggested routes. Second, we discuss how participants experienced the interaction with the app, to address some of the usability and experience issues. Last, we address user preferences, as we reflect on their variability.

Experience of the Suggested Routes

The post-activity questionnaire results showed mixed experiences about the generated routes. Not only between participants, but also between different activities for the same participant. In some cases, great routes were suggested that matched their preferences well (n=20). Participants commented that these suggestions were sometimes very close to their favored walking routes (for activities that happened in familiar environments) (n=12). In these cases, they were impressed and had more confidence to use Pathfinder in unfamiliar environments.

In other cases, participants were less satisfied with the suggested routes. For 14 routes, participants didn’t like (part of) the environment they were guided through, because it was unattractive or boring (n=4), it did not match their input preferences (n=4) or had safety concerns when they were guided through dark alley or tunnels (n=2), along busy roads (n=3) or worried about possible hunters in the area (n=1).

Participants were positive about the fact that Pathfinder helped them to discover new roads, even in familiar environments. These new roads did not even have to be ‘the most beautiful roads’, as 13 participants also reported it was fun to explore and come across unexpected or new things.

Figure 10.4: An example of a route (red) that closely follows the roads that score high (yellow), resulting in a very positive walking experience.

Figure 10.5: An example of a route that seemingly randomly traverses through a high scoring area, resulting in a long route that never really goes far from the starting point.

Figure 10.6: An example of a route that takes almost the same way back and forth, as it is a high scoring road.

“The thing that stood out most is how fun it is to get small variations of walks nearby. It really makes walking a lot more fun and engaging for me.” (P5)

Even at times where Pathfinder was “being funny” (P3), like taking a small tour around the house before starting the route, participants had fun following the route. The downside of these surprises was that these could also be unpleasant at times. Next to perceived unsafety, participants came across blocked roads (n=3) or were directed through narrow firebreaks and sideroads instead of the main walkway (n=2). One participant was suggested to take a small connecting path halfway during a long walk that did not exist, forcing him to stop Pathfinder and use Google Maps to get back.

Multiple participants reported strange detours in their routes or routes that kept ‘zigzagging’ in a small area (n=7), and indicated this to be undesirable, even if it meant more distance in an environment that matches their preferences. Figure 10.5 is a good example of this. Apparently, the shape of the route has a larger impact than we anticipated. Randomly traversing laps or irrelevant detours broke with the flow and gave people the feeling of pointless wandering instead of a positive feeling of achievement. Going back and forth along the same road, as shown in Figure 10.6, yielded similar feedback. When detours were small, participants often indicated that they had skipped these by taking the shorter path, but this was more difficult if the detours were longer or more frequent. Where the intelligent routing engine now focuses on providing a route that scores as high as possible for the entered preferences, without using the same path twice, this desire to ‘walk a nice lap’ is an interesting parameter to consider when moving forward.

Participants made numerous suggestions for environment types that could be integrated in Pathfinder to enrich the experience, some more realistic than others. One participant, who walked with a young child, wanted a route where they would see as many animals as possible. Others indicated they would value a route along points of common interest, that came by a nice place for a drink or a snack somewhere halfway, that allowed them to take a nice route from A to B instead of in a circle, gave them the chance to discover new places by saying it should avoid roads that were already walked, or allowed them to avoid busy roads with traffic lights.

Usability and experiences using the Pathfinder app

As said, we implemented Firebase Analytics to track in-app behavior. The data shows that participants could easily find their way in the app. Generating routes was easy and the time this required was only rarely mentioned as an issue.

“In general, I really liked the app. In a couple of simple clicks, I was able to plan a nice route, and later see an overview of my walks.” (P12)

The suggested activities overview could be improved by showing multiple options at the same time, instead of having to evaluate them one by one, which made direct comparison difficult. Some participants commented they would rather enter the duration of their activity than the distance.

The route illustrations were positively received. Participants enjoyed the look and feel, and it allowed them to understand the route in a simple and playful manner.

“I liked showing the route on the map and seeing the illustrations below, this helped me to familiarize myself with the illustrations. During the route, it did not help me anymore.” (P16)

The illustrations were insightful when they contained enough detail to accurately reflect the surroundings of the route. For example, when the route would switch from residential to a forest, to farmland and back, this would be meaningfully reflected in the visualization. In other cases, when taking a walk through a mostly residential area, the visualization lacked detail and did not help in deciding. Representing iconic buildings or architecture style could for example partly address this challenge. The questionnaires also highlighted that participants found the map view more helpful in familiar environments but saw the most value for the route illustrations in unfamiliar ones.

The navigation map view was the most critiqued view, but participants also spent most time in that view. The turn-by-turn voice navigation also caused some annoyance, as the voice sounded too ‘roboty’ and instructions were not always correct, resulting in an experience of a “nice route with drunk voice assistance” (P17). As a result, participants often walked with their phones in their hands, which was at times raised as undesirable. Also, it was not always clear what the direction of the route was (i.e., if it should be walked clockwise or counterclockwise). This resulted in two instances where Pathfinder indicated to participants that the destination was reached shortly after having started.

Besides issues raised, participants also had multiple feature requests. For example, they requested an option to start a route in a different place than their current location, to be able to edit routes manually, to share walks as a group, to sync with Apple Watch, or to indicate waypoints to attend.

Understanding personal and context-dependent preferences

Pathfinder built on the premise that route preferences are personal and context dependent. The environment sliders in the app could be used to indicate these personal preferences, in a granular way. Participants liked the fact that they had detailed control over their preferences, yet often indicated that it was difficult to determine the exact position of the slider. Next to that, the environment labels, which were directly taken from OpenStreetMap, were not always self-explanatory and could benefit from some meaningful clustering. Grouping environments together –like tree, tree row, and forest into woods– could reduce the number of items to score and make it clearer what was being scored. To investigate how environmental preferences differed between different people and contexts, we visualized and analyzed the environment preferences of all users, for all their activities. Figure 10.8 presents a subset of these visualizations.

The visualizations clearly show that preferences between people varied. Some were rather neutral and only made small adjustments to environments of particular interest (e.g., Figure 10.8.c). Others

Figure 10.7: An example of a not so illustrative illustration.

were more outspoken in their preferences. Their sliders seemed to be carefully positioned and hit outer bounds both positively and negatively (e.g., Figure 10.8.b or Figure 10.8.d). Participants generally show more preference for natural environments, as emphasized by their questionnaire responses. Industrial areas were mostly avoided although there were a few exceptions. The difference in preferences between activities gives us insight into contextual dependencies. Where some people keep their preference similar across activities, with slight variations (e.g., Figure 10.8.c and Figure 10.8.f), others entered different preferences across activities. The motivations behind these are not clearly reflected in the questionnaire. Yet, it emphasizes that preferences are not static, even if it is just because people are interested in trying something new.

10.7 Discussion

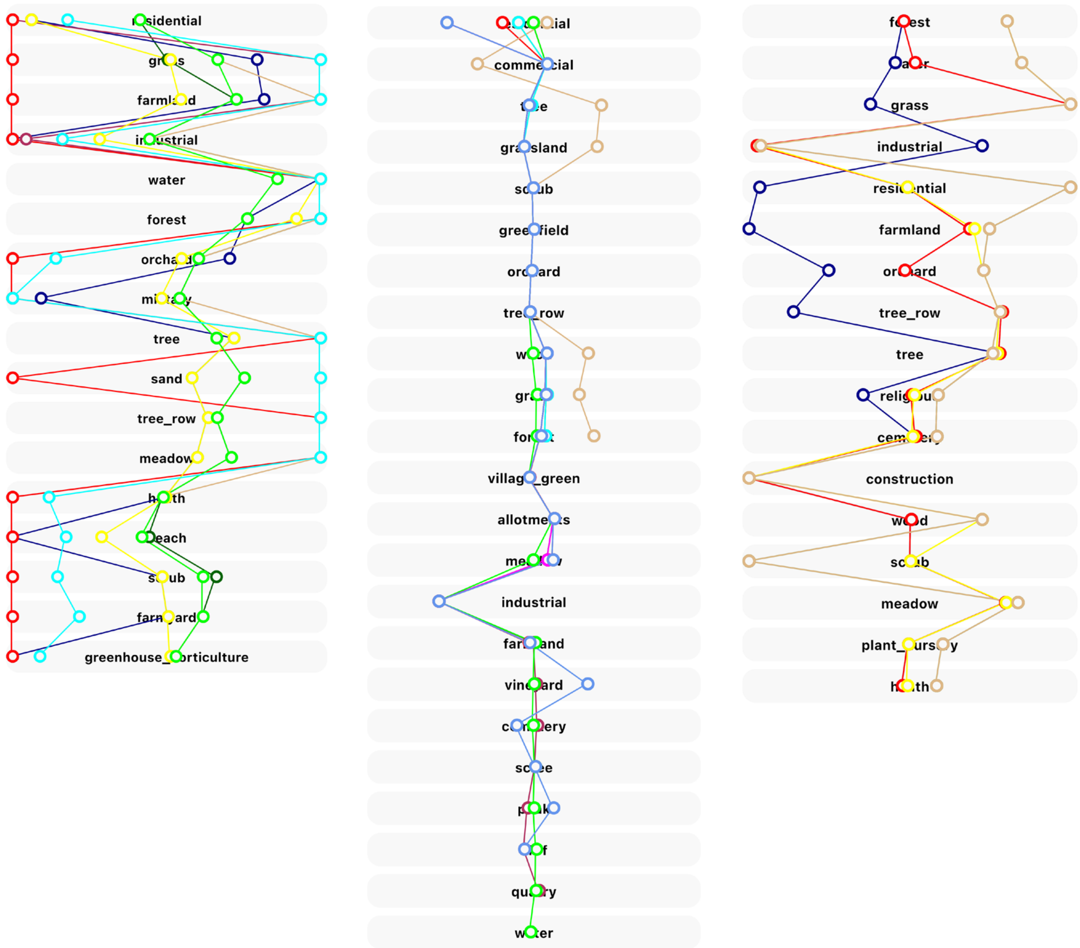
In this chapter, we adopted an alternative perspective on the concept of interActive Environments [266], where it is not the environment itself that is changed but a user's experience of that environment. To explore this concept, we created Pathfinder: a smartphone application that combines detailed environment data with personal preferences of the user to generate a walking route with a great environment experience. We deployed a functional prototype in a field study with 18 participants for 3 weeks. The results show that although more work is needed to solve some recurring issues, there is merit in the concept as people appreciated the personalized environment experiences. To conclude this chapter, we discuss how Pathfinder affected the walking experience of our participants, how Pathfinder was valuable as a vehicle for exploration, and reflect on how our insights have changed our understanding of interActive Environments.

10.7.1 Improving the Walking Experience

While participants only somewhat expected Pathfinder to help them to take longer or more walks in the future, they clearly indicated that using Pathfinder increased their walk enjoyment. The increased enjoyment is mostly attributed to the walks taking place in beautiful or interesting surroundings, indicating that in those cases the app succeeded in suggesting routes that match personal preferences. This is in line with the findings of Coon et al. (2011) who also showed that a pleasant exercise environment positively impacts the experience [313].

Through our study and analysis of user preferences we gave insight into how versatile user preferences are and that these also change based on context. These insights make a strong case for designing more adaptive environment experiences to improve the walking experience. A limitation of this study is that only a third of the logged activities took place in unfamiliar environments, where we expected to find most value of Pathfinder.

Another often mentioned factor that improved the walking experience is exploration and discovery of new or unexpected things, including new roads, places, or objects along the route. This is in line with previous work showing that exploration and discovery can evoke positive emotions and spark curiosity [314,353]. It is possible that part of this explorative behavior of our participants can be attributed to a novelty effect due to taking part in a short study or initial use of the app. A longer-term study is needed to investigate if exploration and discovery remain core values to influence the experience.


water
forest
tree
sand
tree_row
meadow
industrial
industrial
grass
farmland
tree_row
tree
construction
meadow

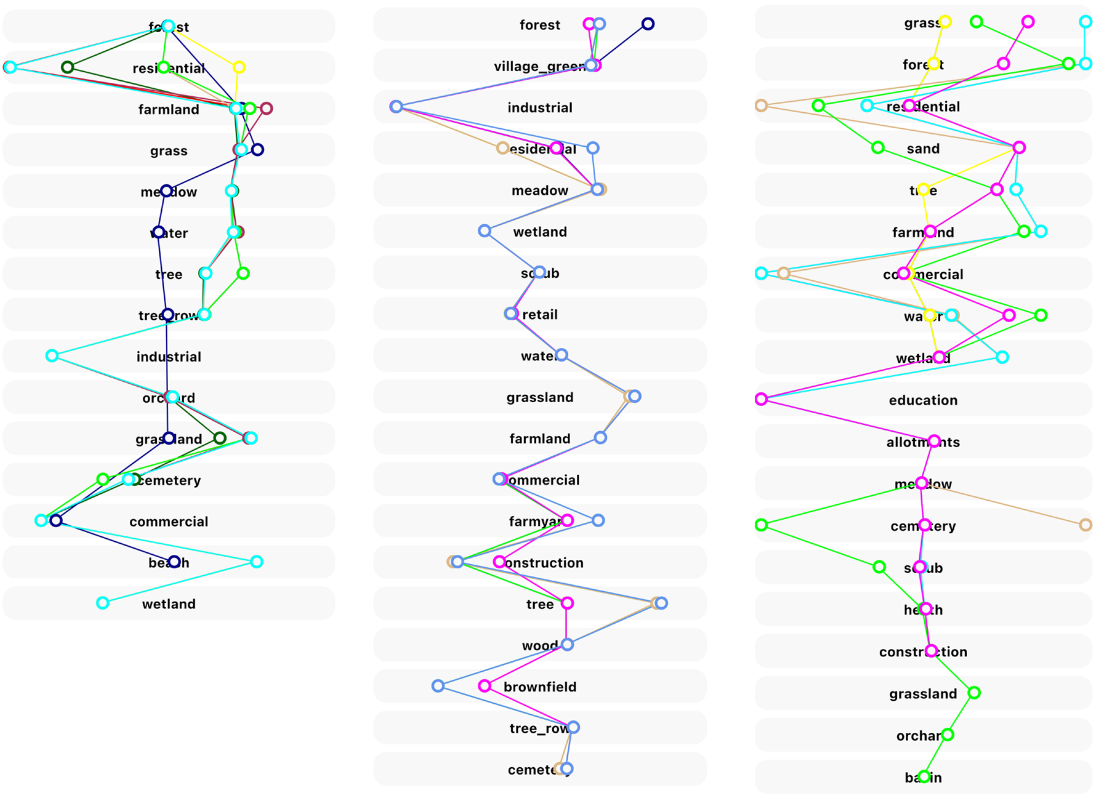


Figure 10.8: Overview of environment preferences of 6 users. Each block represents the environment preference selection of a user. Different colors represent different sessions in which a route was generated. The column length varies as the app only displays environment types that are present in the area.

Next to the effect of the environment, we also outlined how practical aspects such as convenience also played a major role in engaging in physical activity [47,97]. Our exploratory questionnaire showed that people often choose familiar or obvious routes, to save time on preparation and reduce the risk of the activity taking longer than their planning allows. Especially in unfamiliar environments, the time and effort of planning the activity often led to less inspiring routes and increased the barrier of going for a walk at all. Participants shared that Pathfinder was easy to use and quickly gave them route suggestions. This allowed them to explore new places without the hassle of figuring out these new places in advance, which was much appreciated.

These findings indicate the value of a solution that offers an attractive route based on personal preferences. Especially when it is considerate of the user's time by limiting the preparation time, offering insights in the activity duration, and reducing the risk of getting lost.

10.7.2 Pathfinder as a Vehicle for Exploration

We adopted a research-through-design approach [357,358] and used Pathfinder as a vehicle for exploration. We made use of OpenStreetMap data to power the first version of our intelligent routing engine. This allowed us to deploy our prototype on a larger scale, with participants from across Europe, than would have been possible with a more bespoke dataset. At the same time, this also introduced challenges. The accuracy of the app largely depends on the map data, which quality cannot be controlled by us. It does however reflect on the Pathfinder experience, as was exemplified by one very annoyed user that could not find a small road that he was suggested to take.

The data analysis of user preferences proved to be a valuable way of gaining insights into personal and context dependent preferences. As the platform allows for easy integration of additional data streams, and thereby new environment attributes, we immediately learn how popular and important these are for people. In larger scale studies, we could come to understand cultural or regional differences, common denominators, or personal preferences. This data is not only of immense value for us but could also be used to inform Urban Planning & Design activities by local or regional governments.

10.7.3 An Alternative Perspective on InterActive Environments

Through Pathfinder, we explored a new perspective on the concept of interActive Environments that brings together the influential power of the environment with that of personalized and adaptable solutions to encourage physical activity [266]. The examples to date are typically temporary installations that in spite of their initial popularity fail to sustain and scale up [266]. Going beyond the scale of a single plaza or park remains a considerable challenge. The goal of this study was also to explore how we could extend the scale of these interActive Environments, to increase the societal impact of such installations.

Pathfinder presents an interesting alternative perspective here. Although it is not changing characteristics of the environment itself, it is still creating a highly personalized environment experience by reconfiguring route segments with desired properties, guiding a user through an environment that would be very close to their current preferences. Changes in preference will thus result in a different route. Our field study shows that, at times, we were successful in creating great activity environments. This clearly has an impact on how environments are perceived, as it for example allows us to let people experience nature in a dominantly industrial environment by smartly reconfiguring their paths.

Compared to the interActive Environments described by van Renswouw et al. (2021), the digital nature of this solution offers quick and cost-efficient implementation and adaptation. Additionally, the fact that it was built on a globally available dataset, makes it much more scalable. However, there are two sides to this. InterActive Environments that are embedded in physical public space inherit the inclusive properties of the public environment that allow accessibility and potential persuasion of all passersby, regardless of their intentions to change their inactive ways [266]. In the case of Pathfinder, people not only need to look for, find and download the app, but also have to remember to use it over time. In short, using an app for persuasion requires deliberate action of the user each time, while an interactive space that automatically adapts around you can take away this barrier. Therefore, the latter has clear benefits for reaching those who are not actively engaged. On the other hand, the scale of the digital solution has other advantages with regard to accessibility and inclusivity. Instead of requiring travel to specific areas, this solution grants access to this interActive Environment experience to anyone with a smartphone and internet connection, anywhere.

Clearly, both alternatives have their own qualities and should be used to leverage those. For future work, it would be interesting to explore the value of hybrid solutions further. In these hybrid solutions, digital and physical interActive Environments could blend to create an integrated experience to stimulate physical activity and could leverage the scale and the accessibility of both variants.

10.8 Conclusion

In this chapter, we explored an alternative perspective on interActive Environments, where it is not the environment itself that changes, but a user's experience of that environment. To do so, we designed and developed Pathfinder. This design combines established motivational strategies from HCI, and Urban Design practices, into a novel system that creates highly personalized activity routes based on a user's current environment preferences.

Through a three-week in-situ deployment, we then explored everyday use cases of Pathfinder. We discovered how environment preferences are personal and context dependent, and how users' perception of the environment changed because of Pathfinder. These results articulate further how digital representations of the environments can be used as building blocks for interActive Environment experiences that can easily be scaled beyond single locations. Overall, we hope that insights from our research inspire other designers and scholars to pay closer attention to the role of the environment, and how that environment can be personalized, to design for stimulating physical activity.

Acknowledgements

We thank all participants for their contributions. This research is part of the Vitality Living Lab project, financed by Operational Program South Netherlands ERDF 2014–2020.

11 Discussion

11.1 Synthesis of the Main Findings

Though it is well known that a more active lifestyle contributes considerably to overall health, physical activity levels are remaining low [124,127,178,190]. As this constitutes a substantial public health concern, finding effective ways to encourage physical activity and helping people to maintain a more healthy and active lifestyle is an important challenge [159,257,334].

With this work, we set out to contribute to this endeavor by bringing together knowledge and solutions from different research fields in order to improve their potential to stimulate active behavior. Design offers opportunities to encourage, persuade, or push people toward more active behavior in various disciplines, including active environment design [136,148,152,291] and the use of persuasive design and technologies [8,53,67,199].

The research described in this doctoral dissertation builds on and brings together knowledge from active environment design, human-computer interaction, design for behavior change, and design with data to encourage more active behavior. The presented work aims to increase the positive effect of active urban environments by designing and embedding interactive technologies in those spaces. We therefore researched *how to design for active urban environments by integrating data and interactive technology in the design process and the resulting design solutions* in order to stimulate behavioral change toward a more active and healthier lifestyle.

To address this research challenge, we conducted a set of complementary studies addressing three sub-questions. In the following section, we will summarize our main findings regarding these questions.

1. What is already known about active environments and the way they are realized?

Based on a literature review and eleven expert interviews (chapter 2), we defined active environments as *physical places, typically in an urban context, that through their function and design increase physical activity levels of their users*, where we focus on applications in the public space. Next to associations and definitions, we investigated several aspects of active environments. These included the main design elements, strategies, and challenges. Combining a literature study with interviews allowed us to compare views from theory with those from practice, where we saw a clear overlap in important themes related to creating active environments.

We found that the added value of active environments to encourage active behavior is rooted in the accessibility of the public space. Additionally, there is a degree of inevitability of having to enter that environment, which can facilitate exposure and shape behavior through its design. In section 2.3.1, we presented an overview of the strategies that can be used when designing active environments, ranging from open and unobtrusive nudges to increasingly more forcing solutions. We also showed that for active environments to 'work', they must enable active behavior, be accessible and safe. Next to these boundary conditions, we identified environmental aspects that contribute to active behavior: multifunctionality and adaptability, mobility and active transport, attractiveness, 'green and blue' elements, liveliness, and the overall design of a pleasant experience. From our findings, we see that when designing active environments, it is important to regard the entire daily urban system that it will become a part of. This requires integrated and holistic design strategies that acknowledge different stakeholders as well as the socio-cultural, local, and temporal context, which includes variables that change over time.

In bringing together insights from literature and practice, we see that for both the focus remains on listing guidelines and 'ingredients' for active environments, while other important aspects remain largely overlooked. These include the process, its impact on the created solution, and that most interventions target only specific users, context, or technology, and the individual [104]. Additionally, we saw that a large gap in this practice is the virtual absence of monitoring or evaluation of post-occupancy intervention impact [104,278,281], which leaves opportunities to learn from good and bad previous work unused.

To address also these less explored features, we additionally investigated the complex process of creating active environments in section 2.3.2. We provided insights into this complexity, which is mainly caused by the long timeline and the large number of stakeholders involved. Additionally, we discussed how new data applications and smart city technologies could be an answer here (section 2.3.3), as these offer new means of data collection and thus access to previously unattainable data. They can also help track and understand behavior longitudinally and on a large scale, all of which can be used to evaluate results. Next to this, these solutions can enable a more dynamic –or even interactive– environment, offering new potential for active environment design. However, from both our interviews and literature review we conclude that this theory has not yet been translated to application in practice [45].

2. *How can integration of data and (interactive) technology enhance the positive effects of active environments?*

The strategies and elements used to create active environments already encourage active behavior. This effect can be increased by embedded HCI technology, creating Human-Environment Interactions. In chapters 3-7, we saw that by creating a more immersive design, this synergetic combination also optimizes the potential of these technologies to shape meaningful experiences. We call such places *interActive environments*; places designed to increase the physical activity of people (active environments) through the use of interactive technology. By this definition, an interActive environment does not necessarily need the urban context or even a tangible design (as can be seen in chapter 10). It does, however, concern the physical environment. When aiming to improve physical activity at society level, and thus targeting the entire population, the accessibility and reach of the public space make this a uniquely suitable intervention context. Additionally, physical, interactive interventions are probably best suited in an urban or built environment, as they typically require power and/or data connections as well as a minimal number of users to justify the investment. Following our research scope, we therefore focused on applications in the urban public space.

Through their ability to collect and process data, interActive environment solutions allow for new types of feedback [297] and a more adaptable nature of the environment itself. In turn, this enhances their persuasive potential as it enables the use of persuasive technology and supports effective design strategies as described in chapter 3. By being able to adapt to different circumstances, different purposes, and different users, the applied behavior change techniques can be more tailored to the specific situation, which increases their effectiveness. Especially the ability to accommodate users on a more individual level, personalization, is a well-known effective behavior change strategy [28,147,235]. In our research, we investigated how to apply these strategies in an active environment context to create interActive environments.

Through sketches, a benchmark of existing concepts and an analysis of designed artefacts in chapter 3, we propose and initial classification of the design space of interActive environments. We illustrated the different interaction modalities that can be used when designing interActive environments in section 3.4.2, offering several channels of sensory in- and output between the environment and the user. Visual and auditory feedback are the most common interaction modalities we encountered, but also haptic feedback offers many opportunities to augment the experience. Olfactory and gustatory elements, though interesting to contemplate, remain challenging to implement as feedback mechanism in outdoor environments. In section 3.4.2, we identified three main intervention strategies that can be used in interActive environments to create a positive experience or trigger behavior change by nudging people to move more; the use of *fun and gamified* elements, *competitive and performance* related factors, and designs that focus on *social support*. Next to these main categories, other strategies are possible, such as focusing on *overcoming obstacles* or adopting a *provocative design* approach, for instance by using shocking, shaming, or troublemaking to trigger active behavior. Despite the rich opportunities we uncovered through this exploration, our benchmark study and expert interviews show that real-life examples of interActive environments remain somewhat scarce. To realize truly interActive urban environments, we need to translate the poetry and engagement of existing installations to a sustained use in public spaces.

Following this challenge, several of the proposed concepts from chapter 3 are investigated further through a series of design explorations captured as four case studies in chapters 4-7. With these explorations we investigated the potential of interActive environment solutions as well as several less explored angles regarding design to support increased physical activity. Where existing solutions typically trigger a performance based mindset [212,283], we focused on providing a better experience. In presenting compelling designs (triggers), reducing perceived barriers (enables), and overall providing a more pleasant experience (fosters intrinsic motivation), this approach also addresses all three of Fogg's principal factors for behavior change [103].

In chapter 4, we focused on personalized goal setting and guidance through visual feedback to improve motivation and increase physical activity through *Guided by Lights – an adaptive light system for personal guidance.* From this study, we concluded that a combination of personalization, goal setting, visibility and understandability is important to reach these goals. In chapter 5, we aimed to create a more attractive urban running environment using audio feedback through *Sensation – a sonified running track*. Next to the value of audio feedback, we learned that improving the exercise experience can be a powerful strategy to encourage more physical activity that complements the focus on goals and performance often present in such endeavors. In chapter 6, we concentrated on reinforcing existing active behavior through *Discov – an interactive walking experience*. From this study, we learned that curiosity and exploration can be effective motivators for physical activity as they too provide an improved, engaging experience. Additionally, we saw that tying in with existing routines can help lower perceived barriers. For final case study, we focused on stimulating physical activity and social connectedness using the multidimensional attractiveness of water through *Fontana – an interactive water installation* in chapter 7. This study accentuated the inclusive character of interActive environments, the persuasive power of social components, exploration, and fun elements when encouraging active behavior, and the special experiences triggered by designing with water.

These variegated explorations demonstrated the potential of InterActive environments to encourage physical activity through their inclusive and persuasive nature. They highlight the added value that personalized, interactive, and adaptable solutions can bring to active environment initiatives and the different experiences created by using various strategies and interaction modalities. From our design explorations, we learned that introducing adaptability through interactive technologies can strengthen the multifunctionality, personalization, and context-appropriate behavior of the environment. Next to this, it also increases its potential to stay effective in the long term, as it can adjust to new users, new purposes, new needs, or new contexts that may emerge over time (chapter 3). This includes renewing the novelty-effect and the accompanying curiosity by changing its behavior, which can help to keep users engaged for a longer time (chapter 6). At the same time, these case studies also point out the challenges related to moving from temporary, local installations to sustainable and scalable solutions.

3. *How can we use and regard data to address the challenges and opportunities that arise from working at the intersection of disciplines when creating interActive Environments?*

With the advance of smart city concepts on the one side and the shift towards embedded systems and human-environment interactions on the other, the fields of HCI and Urbanism are moving closer together [13,138,151,297]. The increasing amount and quality of data provided by these solutions offer new design opportunities for both fields. At the same time, these transitions also bring new challenges for designers as they have considerable implications for how such spaces are being designed [305].

In chapter 8, we described how to regard a large user-generated dataset from an urban design perspective using an explorative and iterative approach based on data visualizations to learn the relevance of environmental factors for preferable running climates. This study illustrated the possibilities of user-generated big data for the urban planning of active and healthy environments, offering an approach for non-data scientists to gain valuable insights from such a dataset. Still, when designing for interActive environments, both the HCI and urbanism perspectives on data are valuable. A combined approach should aim to leverage each fields' strengths.

Urban planning traditionally looks at the collective interest for a long time span [227], as one design will serve many people for a long period. This asks for a long-term vision that reflects a society's common goals. However, behavior change theory teaches that personalized approaches are more effective than general ones [28,85,147]. Increasing availability of data and digital technologies allow for more flexibility in urban designs; enabling them to adapt to changing times, circumstances or even users. Using this potential and looking at their designs and data from both angles, urban planners can create holistic designs with an increased behavior change.

To create balanced and integrated solutions that possess qualities from both fields, a combined approach must reflect both angles. As we feel these views should not be limited to one field or the other, we introduced two lenses through which to look at data when tackling this interdisciplinary challenge in chapter 9. By introducing a *collective lens* on data, we include the value of the urban population perspective that is needed to design for an adaptive active environment. The *individual lens* on data includes and celebrates individual uniqueness. We deliberately propose the terms *collective* and *individual* instead of *macro* and *micro* to address these perspectives to not only indicate their scale but also emphasize the human-centered focus that's at the core of our approach. Both perspectives play a key role in designing for interActive environments, covering a strong foundation based on collective values, while being able to adapt to the individual people interacting in it, under different circumstances.

Using the *collective* and the *individual lens* offers a way to combine research in the fields of urbanism and HCI. It can help designers focus both on the urban population perspective that considers planning and policy challenges and the personal perspective that celebrated individual uniqueness. This allows for personalization of generic intervention strategies, tailoring them better to specific users. Understanding the design holistically –the small parts, the overall design, how those relate to each other and their context– requires abstract, conceptual and representational thinking [231].

We therefore suggest an iterative approach building on explorative data visualizations that switches lenses continuously throughout the design process. Switching lenses frequently helps to acknowledge the importance of both the detailed properties of interfaces, interactions and personal experiences as well as a broad overview that pays attention to collective needs, context and long term implications [4]. Visual representations of the data make them instantly insightful for the design and/or research-team, helping to identify patterns, outliers and other points of interest. They can additionally be very useful when presenting findings and proceedings to other stakeholders. Including data visualization experts in the team can therefore significantly contribute to gaining insights as well as communicating them. As every iteration brings new insights that raise more questions, this explorative process can be somewhat unpredictable. An open mindset, creativity, and willingness to explore further will help to distill meaningful information from the data.

With blurring boundaries between fields, including interdisciplinary skills in the design team is important. A successful approach asks for a blend of many disciplines, from industrial design, architecture and urban planning to sociology and psychology to computer science and engineering [243]. The development of the next generation of smart and adaptable healthy places calls for a close collaboration between these disciplines.

11.2 Reflections

11.2.1 Interventions in the Urban Public Space

Designing and deploying interventions in the public space comes with specific strengths and opportunities that can be leveraged to improve impact as we have seen in chapters 2-7. At the same time there are also concerns that should be acknowledged. The advantages include low-threshold use and accessibility to all. Because of their accessible and adaptable nature, these public environments also provide a good base for inclusive design solutions (chapter 3) [44,45,247,296].

InterActive environments have the potential to reach everyone in their vicinity, without requiring any prior investment from the user to benefit from the experience, such as buying equipment or paying membership fees. This expands their possible impact to include people with a lower socio-economic status and even the hard-to-reach group of physically inactive people who are not deliberately trying to improve. This is in line with the findings of London (2020) and Zhang (2022), who find that on the one hand, well-designed public spaces can stimulate social interaction [186] and on the other that interactive artistic installations in the public space can bring people together and weaken inequalities [356].

Not only does physical activity have the potential to bring people together, working out together can improve the experience, increase motivation and adherence to exercise routines. Additionally, socializing during physical activity can create a sense of community and belonging, which can have positive effects on mental health (chapter 2) [91,327]. The interconnectedness of physical activity and social context is mentioned by all interview participants in chapter 2, highlighting the importance for designers of (inter)active spaces to acknowledge and address this mutual influence. Urban designs that encourage physical activity can thus simultaneously contribute physical and mental health, social cohesion and integration [166], and even addressing socio-economic inequalities [342]. At the same time, the social benefits are a common motivation to engage in physical activity. From our expert interviews, explorations, and user studies (chapters 2,3,6,7), we learned that indeed part of the potential to engage comes from the attractive pleasant social experience interActive environments can provide by increasing liveliness and exposure to active behavior from others, also normalizing it. But just as certain spatial designs can also discourage physical activity, so can social factors. Social norms and attitudes toward physical activities can constitute barriers, for instance when feeling self-conscious from exposure to spectators, fearing judgement or criticism from peers, hinders participation in certain activities [166]. Other social barriers include scheduling conflicts with training partners, lack of social support, and a normalized inactive lifestyle [145,152]. As social context can vary greatly between different places, both on a micro and macro scale, this may well influence the effectiveness of certain design solutions [342]. Urban designers who aim to encourage physical activity through their work should therefore also acknowledge and address this social context in their design scope.

The rapid advance of technology allows for the integration of sensing and data capacities within interActive environment interventions. We have seen in chapters 8, 9, and 10 that these can provide key insights to urban designers, municipalities or policy makers to monitor effects, intervention opportunities, and further improve their policies and designs. In addition to providing valuable insights, these new design opportunities offer the ability to create more adaptable solutions that can be better tailored to various users and circumstances. This increased adaptability has the potential to maximize the benefits that can be gained from creating (inter)Active environment solutions. These societal benefits of improved health and quality of life on a population level make the urban public space a suitable place for design interventions aimed at increasing physical activity in the general population [104,146,257].

On the downside, building physical, interactive installations in the public space will require an investment and commitment from the government and/or community. Building them takes money, time, and getting all stakeholders on board. Then after implementation these installations still need regular maintenance, all of which also make it difficult to scale up these solutions (chapters 2-3). However, the scale and maintenance challenges may be limited by using smart, durable design, low-maintenance hardware, and a digital layer that allows for interconnected devices and opportunities for remote adjustments (chapter 10).

Another aspect to consider is the effect of such installations on other people nearby. This includes people that are visiting the interActive environment area, but also people who work or live nearby. Sound, light and people already interacting can increase the attractiveness of the installation and draw in new users by triggering curiosity and through exposure (chapters 2-7). For others, the sounds, lights, or increased liveliness can still improve their experience of the area, even when they do not interact with the installation (chapter 5). Increased attraction can also lead to unintended use of the installation, which can be either positive (for instance when children use it for play)or undesirable. Undesired unintended use includes use that creates dangerous conditions (for instance through climbing on– or jumping off equipment or splashing water that creates slippery surfaces) and situations that hinder other people (for instance repeating or loud sounds or breaking the equipment). Undesired unintended use should ideally be identified (through user testing) during the design phase and prevented.

However, use of sound and light, data and/or cameras can also have negative effect on other people nearby. Sounds and lights can become a nuisance for people who reside nearby and therefore end up having it constantly in the background. For others it may alter their experience in an unwanted way, for instance by 'breaking' the natural park land- or soundscape with artificial hardware, light or sounds. Camera's, other visible sensors, or notifications/requests for (personal) data use can also repel people who are wary of what other purposes their data could be used for without their knowledge.

Different types of urban space

There are many different types of public space, even within our focus on the urban context [52]. Our expert interviews (chapter 2) illustrated that differences in local culture are a significant and important factor when designing active or interActive environments, as they play a big role in the use and purpose of the public space. Next to this, also the contrast between a square and a park, a modern or a historic area, and residential, commercial, or industrial districts, illustrates the diversity of contexts that can occur within the urban public space. Other influential factors include building density and level of high-rise, street and sidewalk width, infrastructure, soundscape and even climate. Next to this, a city is highly dynamic. Not only are there the constant changes of traffic streams and weather conditions, but also the more gradual fundamental changes over longer periods of time such as an aging, growing, or otherwise changing population, infrastructure adjustments, and (re)building projects that alter the role and conditions of the urban public space [19,70]. All these variables can influence what would be the most suitable type, execution, and location for interActive environment solutions. Considering this context during the design process is important to create successful interActive environments. We learned from our benchmark study (chapter 3) that examples of true interActive environments are somewhat scarce. With a limited number of actual interActive environment examples available for comparison, it is hard to say which type of context would be best to focus on when considering interActive environment sites.

It makes sense to make use of places that already offer part of the desired solution, such as existing attractive and active environments (parks and green areas, neighborhood playgrounds, or sporting complexes), preferably accessible and conveniently located (chapter 2). The positive effects of these places can then be enhanced through interactive installations. On the other hand, re-designing unattractive or uninspiring places into interActive environments increases the number of activating places and thus their reach, while at the same time improving the cityscape. Consulting citizens and other stakeholders can be a solution to find the best intervention location in specific contexts [16,109,216,247].

Altering the public space

Next to what is possible, there is the question of what kind of interventions are appropriate in the public space. For a conceptual change in the purpose of the public space, such as using it to encourage active behavior, there should be a significant societal stake and interest. As the public space 'belongs to everyone', projects there should benefit and appeal to a majority of people using it, as well as contribute to the society they are part of. In the context of interActive environments, this requires designers and policy makers to regard the role of physical activity and the importance of a healthy lifestyle in that society. The increasing urgency and awareness of the health consequences of physical inactivity have put this topic high on the societal agenda as it concerns a large part of the population. This makes the public space a suitable medium to use when addressing the population wide issue of insufficient physical activity and thus a fitting place to create interActive environments. Also here, consulting citizens in the process can improve alignment and increase the effectiveness of the chosen solution. Through an additional smart layer, the realized environments could even help monitor effectiveness of the intervention by collecting sensor and/or user-generated data about its use and impact (chapters 2, 9) [109,279].

Our expert interviews taught us that realizing design solutions in the public space additionally comes with some practical organizational challenges, which in general become larger as the scale of the intervention increases. Questions arise related to stakeholders and their involvement, such as 'who initiates?', 'who has decision power?', 'who brings the money?', 'who also needs to give their opinion/permission?', 'who will take care of maintenance? and for how long?'. As we have seen in chapter 2, the complexity here is related to the number of stakeholders that need to be involved in order to cover all these points. In general, we can say that the more complex the process, the higher the urgency needs to be to intervene. For semi-public spaces such as a company campus, this is relatively straightforward. The board or campus management decides, allocates the funds, and the process can start. This leads to a relatively short timeframe. Of course, they –or the design team– may still collect data about future users and their wishes to further refine the concept. The desire to change here can arise from employee wellbeing but may well be related to the company image or marketing goals.

When an area is completely being re-designed and an interActive environment is shaped as part of the project, it can 'piggyback' on the established process in terms of planning, financing, and decision making. Consequently, this would increase the realization time and number of involved stakeholders to those of an area redesign rather than an intervention in a pre-existing space. Still, as a part of a larger plan, the entire area can be shaped to form an integrated whole. The interActive environment will be designed as a natural part of this and since the whole area will be modern and new, futuristic elements or the fact that it will 'change' the environment will become less of an issue. For this situation, the urgency largely comes from a need to upgrade or modernize the entire area, including buildings and infrastructure. Incorporating an urban space intervention, such as an interActive environment, requires comparatively few extra steps and resources as stakeholders are already involved and the area will be rebuilt anyway. It can therefore be seen as a valuable add-on but does not have to justify the entire development. To alter existing public space, however, that is the case. The urgency therefore needs to be high to outweigh the trouble and cost of the alterations.

11.2.2 At the Intersection of Disciplines

In the field of urban design and planning, the shift towards smart cities that build on data to address logistic, sustainability, and social challenges indicates a transition towards technology-enhanced environments. HCI design in turn evolves to the realm of physical space as technology is increasingly integrated in the environment, creating human-environment interactions [297,306] and thus blending with spatial design. Moving towards each other, these developments create a bridge between the HCI and urban design domains.

We have already discussed the differences in scale, timeline, and user perspective between HCI or industrial design and urban design and planning. In researching interActive environments, we position ourselves at the emerging intersection between these two fields. But both these main expertise areas and the presented work on interActive environments draw on several additional disciplines, including data science and visualization, and psychology. Next to exciting new opportunities, such transdisciplinary work also brings certain challenges as research theories, methods and terminology vary [34]. In bringing all these fields together, we have encountered several of those challenges.

With the application of interdisciplinary tools and approaches becoming popular in many sectors and scientific fields, acknowledging and addressing these challenges is becoming more relevant [34,37,140,175]. Throughout our own interdisciplinary process, we have experienced several of them, which we will briefly address below. In a research context, it is difficult and laborious –if not unattainable– to reach the same level of depth for each discipline as a mono-disciplinary work. While a proper understanding of relevant aspects of each field is required to build on, domain-specific technicalities are of less importance when looking for overarching values and complementary qualities. Instead, broadening the scope and integrating knowledge from different disciplines is a challenging endeavor that requires an open mind and creative attitude to address. We have noticed, however, that this is not always evident, both for researchers and reviewers of their work. A balance must be found between gaining enough understanding of the topic at hand without going down the rabbit hole of discipline-specific details and losing track of the overarching goal. Literature on the practice of interdisciplinarity states that the lingering challenges include competing definitions, standards, and approaches between fields [140,175]. Domain specificity of expertise and scientific practice may therefore play an important role in the experienced difficulty of interdisciplinary work [189]. For researchers, studying the same topic from various paradigms can feel chaotic and confusing as one concept may have different names between fields, while other terms are the same but have different meanings. Additionally, the angle and emphasis of studies may differ, which can cause elements considered 'essential' in one discipline to be barely discussed in the other. This makes it hard to compare works and draw conclusions. As publication venues are typically connected to research areas and reviewers are often experts in a specific field, multidisciplinary work where that specific topic only represents part of the submission is likely to be judged largely on that part, through the lens of that field. Differences between disciplines in what constitutes 'the right' method, contribution type, or even writing style can thus easily lead to misinterpretation or even devaluation of the work [34,189]. Interdisciplinary researchers should consider this possibility when selecting a publication venue.

Though introducing knowledge and solutions of another field can help to address long-existing gaps or issues, this also brings the risk of introducing related weaknesses with it. Embedding smart and connected technology to a physical space, for instance, increases adaptability and enables remote alterations. At the same time this introduces vulnerabilities related to software hacking and breakability of the physical elements. Designers should be aware of these risks when creating combined solutions, aiming to leverage strengths from each part to reduce the other's weaknesses.

Despite these troubles, the intersection remains a fascinating place to be and learn. It offers new design opportunities and a need for creative merging or development of appropriate methods. Following the global trends of technology becoming more ubiquitous and interconnected, traditionally separated disciplines find themselves increasingly co-dependent. These developments ask for new and multidisciplinary approaches, which can only be developed when valuing and understanding the related fields equally. This comprehension can also be a great asset when communicating with different stakeholders or in multidisciplinary teams. Knowledge of what each party brings to the table and their way of working can increase mutual understanding, avoid miscommunications, and streamline the process.

Looking at the presented arguments, working at the intersection of disciplines may well be worth the additional challenges. However, the combination must make sense; there should be a consolidated goal and the expertises should complement each other, leading to stronger outcomes. The exact nature of the best integrated approach depends on specifics about the goal and combined expertise. Creating a universal framework for multi or transdisciplinary work has not been part of our research objectives. However, in this work we presented several handles for and examples of such an integrated approach in the context of designing for behavior change to support physical activity as a part of a healthy lifestyle. This large societal problem constitutes the overarching goal as the base of the collaboration. As both fields have been working towards solutions, we have identified and combined these in chapters 2-7, aiming to leverage their strengths and minimizing their weaknesses. Additionally, both fields traditionally work at a very different scale which also shaped their perspectives on users, adaptability, and use of data. In chapters 8 and 9, we have therefore identified these views and their added values towards the common goal, again offering a way to find the best of both worlds. Finally, both combined angles are brought together in a final case study in chapter 10.

As we have seen, the Urban and HCI design fields are already moving towards each other. These trends indicate that future solutions will benefit from integrated approaches that reflect strengths from both sides.

11.2.3 Smart Solutions and Designing with Data

Data plays an instrumental role in smart, adaptable, and interactive environments as it is the fuel to drive such solutions [160,222,242]. However, data as a dynamic enabler is not yet a standard topic in urbanism. In urban design and planning, data is increasingly used for analytical purposes and informed decision making, with big data and crowd dynamics offering longitudinal system observations and insights into complex behavioral patterns [10,18,55,137]. Visualizing these data can be a powerful tool to both gain and communicate such insights [49,123,287]. The focus here lies on general trends, patterns and averages provided by the aggregated data [227]. Still, if cities and environments grow to be adaptable, they should be able to adapt on a more individual level. This would improve the personal experience of the space and increase their potential to encourage more active behavior, as tailored approaches are most effective in persuasion [28,85,147]. For this we need data to focus on details, nuances and people's idiosyncrasies rather than only generic insights on population-level [170]. This approach of using data to tell meaningful stories [59], pinpointing individual traits and characteristics is often used in HCI. It is essential in gaining the empathic understanding that is needed to design systems that can really adapt to people's individual needs. Explorative data visualizations, with high levels of individual detail, have proven to be a valuable tool in this [231,287]. At the same time, moving from artifact to environment introduces challenges of scale and accompanying inflexibility unfamiliar to the HCI community. With this comes a need for a more large-scale and birdseye perspective, offering reliable insights in general behavior and trends. This view is still rather unexplored in HCI literature [4].

In becoming more 'smart', products and environments are increasingly equipped with the means to collect data [109,297]. Additionally, user-generated data is provided by a large group of people tracking their own behavior through apps and wearable devices [57,96,187]. The increasing amounts of both user-generated and environmental data at our disposal provide new insights into personal behavior and preference. This data and the knowledge it provides support more context aware and tailored interventions, increasing their potential impact on user behavior. The 'smart', digital layer they provide, offers additional opportunities as it enables interconnected devices, further personalization, and remote updates or maintenance. The connection of separate devices can make them function as parts of one large integrated solution that provides a harmonized experience. This way, a digital layer can greatly reduce scaling barriers.

These advantages of 'smart' solutions have led them to be integrated into a wide variety of systems and objects, varying in scale from wearables and home devices to smart-city initiatives. Driving all these systems, the role of data has consequently grown with it. As it is now embedded in so many parts of society, a critical view is required regarding these data streams.

Risks to consider

An important note is that when the system makes the decisions, people are losing control. Though the term 'smart' is used for a collection of integrated IoT and AI solutions, it does not always create a system that is indeed 'smart' [198,305]. Countless examples exist of automated systems that 'just don't get it' the way a human would, combined into three basic problem categories by Streitz (2019): *Inability and error-prone behavior of AI*, for example self-driving cars that mis-assess traffic signs or situations; *Rigidity*, such as fully automated call-centers that have no option that matches your question or receiving online advertisements for an item you just bought; and *Missing transparency, traceability and accountability*, meaning that in evolving and becoming more complex, AI system behavior will lose transparency, comprehensibility and thus accountability. As AI algorithms are improved to include more variables and function well in complicated situations, they can become highly convoluted. This means that the rationale behind decisions becomes incomprehensible, and argumentation untraceable. The system is no longer transparent as motives and even desired outcomes are no longer clear. Consequently, this makes it very hard to find who is accountable when something goes wrong [305].

When working with and even basing system behavior on data, the risk of bias is important to consider. The collected data may not be representative of the broader population, especially when collection is limited to a small number of users, a specific location or context, or a short period of time. This means that the collected data is not always neutral, and may not reflect the truth about our cities [32,123,291] As a result, algorithms and other decision-making processes that are based on this data may be fitted towards a certain setting or biased towards the dominant group of users in its sample. This could lead to suboptimal behavior in another context or even to unfair treatment of other users, which is a serious ethical concern. Especially when aware of being observed, users may reflect intervention bias when they exhibit the perceived 'desired behavior', experience shyness, or as a result from the novelty effect [158,272,343]. Addressing the issue of bias comes from two sides. On the one hand, bias should be limited where possible by including a representative user base and striving for unobtrusive observations as well as choosing the right research context and duration for the data collection. As this will likely still not produce a perfect data sample, researchers and designers should be aware of the under- or overrepresented groups and adjust their designs, systems, or conclusions accordingly.

Looking at the data itself, there is still much to consider about the collection and handling of such data. There are several potential ethical implications of using data in smart or interactive environments, particularly when it comes to privacy. A major concern here is that such data can be used to identify individuals and/or uncover sensitive information about them. This risk increases when the collected data is combined with other data sources to bring comprehensive profiling, more context, detail, or long-term observations, to the point where their movements or behavior can be constantly tracked [71,305,355]. The potential privacy risk is thus substantial, especially when considering what such surveillance data could reveal in the hands of malicious parties [86,111].

Rules and Guidelines

To protect their citizens from such distressing scenarios, the European Union has adopted the General Data Protection Regulation (GDPR) in 2016 (enforced since 2018), which regulates storing, processing, collecting and disclosing of data with the goal to protect their citizen's privacy and give them more control about the use of their data [9,99]. Regarding data collection in the public environment, it states that personal data must be used for specific, explicitly defined purposes, and individuals must be informed about how their data will be used. It also requires that organizations take appropriate measures to ensure the security and confidentiality of personal data. For designers of such systems, the best approach is to be transparent about how the data will be used and take appropriate measures to protect the privacy and security of individuals. This may involve implementing strict privacy policies, anonymizing data where possible, and being selective in what data is collected in the first place.

Zooming in on smart city solutions, the Dutch Data Protection Authority additionally presented recommendations for municipalities that (intend to) collect data in public spaces through smart sensors and measuring devices [86]. They stress the importance of a public space where citizens can move freely and unobserved, to avoid heading towards or facilitating a surveillance society. To safeguard this without rejecting smart solutions altogether, they offer practical guidelines for this, keeping the GDPR framework as base and boundary. These guidelines include striving for applications or solutions that require as little personal data collection as possible to reach their goal, preferring none; determining concrete and measurable objectives that allow determination of the smart city application; identifying next steps if it proves unsuccessful or has unwanted side effects; ensuring lawful data collection and transparency about the collection of (personal) data in public areas (GDPR); including 'data subjects' (citizens) by asking and following up on their views, specifically for high(er) risk cases; ensuring adequate knowledge about digitalization and technology within the municipal council; and remaining aware that ethics cannot be replaced by a set of laws and regulations.

Such guidelines can offer structure and direction to designers of interactive or connected solutions. It forces them to carefully assess what data should be collected for what purpose, how it should be collected, who gets access to it and what other decisions or (system) behavior will be influenced by it. Answering these questions remains important when considering data ethics, even if for the intended project location no such regulations are in place. At the same time, regulations cannot cover every aspect of ethical deliberations, which means that designers should not focus on 'checking the required boxes' but still thoroughly consider all ethical implications of their design.

11.2.4 The Dark Side of Persuasive Design

In this work, we built on knowledge about designing for behavior change, including personalization [28,30,147] and nudging [50,129,310]. We have described how such techniques can be used to encourage active behavior, supporting people in achieving and maintaining a healthier lifestyle and contributing to the societal health issues caused by physical inactivity. Even with the best intentions, these persuasions always aim to steer behavior towards a certain norm, which is determined by their designer. In our case, this 'norm' was more active behavior to reduce health risks and improve quality of life, based on definitions and guidelines derived from related research and WHO standards [33,134,159,238,257,336,339]. These techniques to influence behavior can unfortunately also be used for less philanthropic objectives. In interface and digital design this is referred to as deceptive design or *dark patterns*. The HCI community is therefore increasingly engaged in a debate over the use of persuasive design for both causes [129]. Critics argue that it can be devious or even unethical when it is used to trick or manipulate users into doing things they may not otherwise have chosen [197]. As seeing through and resisting these techniques requires a level of awareness and understanding of the system, it presents an increased risk to control and exploit vulnerable individuals.

Additionally, the use of persuasive technology raises concerns about privacy and data security, as the personal information collected through these technologies can be used for nefarious purposes. Websites, apps, and social media harvest all sorts of data, often without informing the people providing it about the exact nature and goal of this collection. Data has become a valuable resource and can be sold to third parties for attractive fees. By combining sources, companies and governments can use this data to create detailed user profiles and even identify people, adding significantly to the potential for data exploitation [269]. For designers who aim to use persuasive techniques it is thus important to carefully consider these potential downsides and ensure transparency and an overall ethical use case.

11.3 Limitations

The presented work has several limitations. Specific limitations for individual studies are discussed in the corresponding chapters. Here we will review overarching topics relevant to this research.

In the context of designing for behavior change, the presented studies had rather short test periods. Ranging from several sessions to four weeks, none of them lasted long enough to assess longitudinal impact. The approach we adopted fits our goal to investigate the potential of interActive environments. This new concept follows the evolution of two main research fields that respond to rapidly developing technology. In our quest to investigate the applications, approaches, and impact of this new concept, an explorative approach that includes a diverse collection of shorter and iterative studies was best suited to get a comprehensive understanding of the possibilities. As a result, it is possible that parts of the participants' responses are influenced by the novelty effect. Though this work offers valuable insights in the application and potential of interActive environments, iterating further and including more long-term studies can help to consolidate the findings presented in this thesis.

The nature of the case studies also allowed a limited number of participants. Considering the selection methods used (e.g., posting the invitation in a certain social media group or using snowball sampling), participants may have represented one group better than another, resulting in some bias. Several of the described studies make use of data from external sources (chapters 8, 9, 10). Also for such data, it is important to note the nature of that data and acknowledge possible inherent bias. For each study, the selection method is described in the corresponding chapter.

Finally, this research has taken place in a specific region of the world, being north-west Europe, with a majority in the Netherlands. Though we have strived to keep this work universally applicable by basing it on international literature and standards, local and cultural factors may still have played a part in participant behavior as well as in researcher's methods and interpretations.

11.4 Contributions

The research presented in this dissertation has brought together knowledge about stimulating and encouraging physical activity from the fields of active environment design, human-computer interaction, design for behavior change, and design with data. What sets this thesis apart from existing work on using IT to encourage active behavior is the environmental embedding, which alters the scale and context from designing a product to designing an urban space. Simultaneously, it adds interaction design, adaptability, and designing with data to the body of knowledge describing active environment design.

Through a collection of complementary studies, we have investigated how to bring these elements together and so increase the positive effect of active urban environments by designing and embedding interactive technologies in those spaces. Describing thas work, this thesis makes several contributions to both the theory and practice of designing environmentally embedded and interactive solutions to encourage active behavior. In this section, we will outline them following the contribution types defined by Wobbrock (2012) [347,348].

We offer *empirical* contributions by presenting new findings based on observation and data-gathering in chapters 2-10. We have collected and used multifarious data from pre-existing available datasets that needed custom modification to become usable, and new data gathering. The new data was collected through a variety of methods, including field studies, interviews, user tests, surveys, and workshops.

Starting from a broad investigation of the context (chapters 1 and 2), we continue our exploration on two parallel paths that further examine the main opportunities found. We present five design *artifacts* that were used to research new applications and opportunities of interActive environment solutions (chapters 4, 5, 6, 7, and 10).

With a wide variety of apps and technologies to support physical activity and running already on the market [142,200], we also use these design explorations to investigate several less explored angles in this field. Where many solutions focus on increasing performance and reaching goals, we adopt a human-centered focus in our approach and aim to motivate by providing a better experience. We do this by using environmentally embedded interactive solutions to create more attractive exercise environments (*Sensation, Pathfinder, Fontana*); to encourag fun, playful interactions and exploration (*Discov, Fontana*); to offer a challenge (*Guided by Lights, Discov, Fontana*); to lower barriers (*Pathfinder, Discov*); foster social connection (*Fontana, Discov*); and stimulate mindfulness (*Sensation, Discov*); applying tailored and personalized elements (*Pathfinder, Sensation, Guided by Lights, Discov*); and scalable solutions that provide a harmonized experience throughout a large area (*Pathfinder, Discov*). We deployed these prototypes for in-the-field user testing to iteratively improve their concepts and further investigate their potential. Next to gaining research insights and user feedback that allowed for iterative improvement of our concepts and methods, building and deploying these prototypes also offered several additional valuable insights. These included detecting and addressing practical design issues (e.g., establishing durability or combining electronics with water), knowledge on how to set up data handling compliant with ethical regulations (GDPR), how to define the best locations to deploy a design, to consider additional stakeholders, and how to get local authorities on board.

This work also brings smaller *theoretical* and *methodological* contributions, as it transcends traditional discipline boundaries and bridges between research fields, offering insights and recommendations for a combined approach. We propose a comprehensive definition of the term *active environments* and introduce a new, interdisciplinary concept by combining them with HCI technologies which we call *interActive environments*. We also introduce a *collective* and *individual lens* to regard user-generated big data when designing for interActive environments and demonstrate their value for an integrated design process. Finally, we present an alternative perspective on the interActive environment concept by creating *Pathfinder*, introducing a new way to shape highly adaptable and personalized experiences in the existing physical environment through the use of a smart digital layer.

11.5 Implications and Recommendations for the Future

Physical inactivity is a complicated problem, especially on a society level. It is not one mishap caused by a single poor decision but rather the result of a complex mix of circumstances and behavior that manifests over time and only leads to health issues even further down the road. This makes it an elusive problem that will need a large collection of changes throughout the entire system to address it. One intervention alone cannot solve this issue. Though this adds to the challenge of convincing investors and stakeholders of their value, is does not mean that single interventions are pointless. If they help to improve even one part of this complex problem, they are valuable. Because then enough interventions combined will eventually have a significant society-wide impact.

In this dissertation, we have presented a collection of design solutions and approaches aimed at contributing to this goal, both at the society and individual levels. We have brought together techniques and solutions aimed at encouraging active behavior from different disciplines with a focusing on design, HCI and urbanism, creating environmentally embedded smart and interactive solutions that leverage the strengths of these combined fields. We have showed the potential of these interActive environments to support healthy active behavior, as well as learning from and adapting to user behavior and changing contexts. However, more large-scale and long-term research is needed to further corroborate these findings.

11.5.1 Looking to the Future

The shift toward smart cities has the potential to significantly impact the practice of designing and planning urban environments. This leads to new and more innovative ways of designing and managing cities but also requires a deeper understanding of new technologies, data, and IT-related disciplines [45,279,297]. Creating these cities of the future is therefore an increasingly multidisciplinary challenge.

The opportunities presented by data and interactive technologies have also resulted in 'smart' designs and solutions that introduce computers to all parts of daily life. These developments lead to evermore interconnected and embedded systems, with designers shaping interactions with spaces and systems rather than stand-alone products [138,297]. This introduces a new scale and context dependency to their design challenge that asks for additional expertise.

The implementation of more data-driven decision-making can reduce the number of design decisions based on assumptions and intuition. Moving from assumptions to evidence in the form of data can improve the quality of the final concept and ease the design process. At the same time, answering the right questions with the right data then becomes critical [155,198,301], adding a new array of challenges. Both designers and urban planners can use the opportunities provided by the growing body of available data to inform their decisions but will have to remain aware of the limitations of the datasets and the value of their knowledge about design. This way, they can combine new knowledge and technology with their existing skills to address all aspects of their complicated design challenges.

Greater flexibility, adaptability, and even interactivity allow formerly static environments to adjust to changing conditions, emerging technologies, and to different users. This could lead to urban design and planning practices that are more responsive to the dynamic needs of cities and citizens, and that are able to evolve over time (chapters 3, 8, 9, 10). It also allows for a more iterative design approach, as adjustments to already implemented solutions can be made through the digital layer, without requiring expensive alterations of the physical components. Designers can use these advantages of smart and interactive solutions to further prioritize the health and wellbeing of their citizens. This is in line with the growing focus on sustainability and quality of life [13,31].

Safeguarding the privacy of citizens remains an important argument to consider when deciding about accepting or rejecting smart, embedded, or interActive solutions in the public space. At the same time, they offer a variety of opportunities, from resource and energy use reduction to supporting public health and social cohesion. A balance should thus be found that capitalizes on these advantages without sacrificing citizens' rights to privacy and transparency of their data use. Establishing a framework of practical guidelines for local governments as suggested by the DDP [86] can help to select projects that are anticipated to bring significant benefits to the city and/or its residents and respect citizen rights. Open communication about the location and type of data collection, as well as its use and by whom, is also essential and should therefore be included in those guidelines. As it is impractical to place signs all over a 'smart' area to alert people of the sensors present and their purposes, an accessible online platform with up-to-date information and links to relevant websites seems a good solution for this. At strategically relevant places in the city, signs can still be placed that refer people to this platform for more information.

Trends in technology development suggest that the blurring of borders between research fields is likely to continue. Environments and cities are becoming smart while human-computer interactions are moving towards human-environment interactions, both having a strongly increased potential for sensor-based data collection. This data brings a rich potential, to create interactive solutions but also for creating learning and adaptable systems and more structural post-occupancy impact monitoring and evaluation. When the public space is used as a design for behavior change, a stronger link emerges between urban planning and behavior psychology, which emphasizes the need for a user-centered approach while highlighting the importance of proper ethical guidelines and balancing the desires and rights of the collective user group with those of the individual. This calls for development of a conceptual model to understand how the combined factors of HCI, active environment design and social practices (re)shape behavior. Future design teams as well as their strategies need to represent all the disciplines that come together in the envisioned transdisciplinary solutions in order to reach their full potential.

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Appendices

Appendix A | Semi-Structured Interview Guide

Semi-structured interviews were conducted in Dutch and translated to English

About you

Who are you? What is your job title and job description?

What is your professional and educational background? Work experience?

How does your job relate to Active Environments?

Photo Elicitation - Examples of Active Environments

Preparation task: In preparation of this interview, could you please come up with 3 examples (you can of course bring more!) of what you would consider as an Active Environment. It does not have to be a project you have been involved in, but just a good illustration of the topic.

During the interview: Let's look at the examples you have been providing. Can you tell me what these are and why they are considered Active Environments? What is the strategy they use to trigger people?

Active Environments

How do you define Active Environments? (what does this mean to you?)

What is the objective of Active Environments according to you?

What do you see as main triggers for people to be active?

How does it translate into the process or solution you would implement?

What is the added value of acting at the environment level to trigger people into being active?

Collecting and Making Sense of Data

What type of data is usually collected to conduct projects on Active Environments? (This could be anything you defined as data / source of information)

Why? / What kind of questions did you/the team (hope to) answer with these data?

How do you make sense of the collected data? (summaries, visuals, analysis, …)

What are you using the data for? (can be not to improve but to satisfy client/marketing, …)

How do you monitor or evaluate the success of the project? (again data)

→ after how long/ length of intervals between measurements if applicable

Designing with data and in real life

How did you use data in the design/decision process?

Access to what data would (have) improve(d) the design?

What type of data do you wish you would have but is typically missing?

Illustrative Example

During this interview, you mentioned a couple of examples of Active Environments. Let's focus on one specifically.

- Can you describe an example of an Active Environment project you have been involved in? Ideally, walking us through the project from the start to the implementation? (steps and general timespan)
    - Follow-up: What happened next? Who was involved at this stage? What was your role? Why? Can you give me more details?
    - What were the criteria of success and (if so) how were they assessed?
    - In this project what kind of data did you collect? (before, but if applicable also during and after the study)
- If the existing design is an interactive solution:
    - What kind of data is collected by the design?
    - Is this only used for interactivity or also for evaluation/research?
    - How is it processed? / how 'smart' is the design?
    - How do you handle GDPR and privacy issues?

Towards interactive environments

The increase of digital technologies and applications enables a new generation of more interactive or even smart environments. How do you see this development in the context of active environments?

How do you see the opportunities, pro's and con's of using such technologies to create more personalized environments?

Why would personalization / gamification be effective in the design of Active Environments?

How can one concretely design for it (or approach it)?

Appendix B | Examples of Active Environments

	Example of Active Environment	Additional description (if provided)
P1	Expansion District in Almere (NL)	The complete recreative, active program 'reaches into the back yard'
	Bicycle streets and low-traffic residential areas	Space for pedestrians and bikers, who have preference here over cars
P2	Gymnasium	Environment that triggers activity for children and adults
	Natural outdoor swimming facility (with some play equipment)	I experience [and therefore associate] free time and leisure facilities with much more activity than a workplace
P3	Grass field in park	
	Playground	
	Bike lane	
	Calisthenics equipment	
	Benches	To make elderly people move, you need to place benches.
P4	Twinkeltegels	Interactive light tiles in sidewalk or play area
	Eckart Smart Exercise Route (NL)	Path with interactive tiles that light up sequentially with a pre-set pace
	High Tech Campus Eindhoven (NL)	Attractive outdoor areas, combined with one central lunch location. Invites people to walk there and lowers barriers to extend that walk
	Social Stairs (NL)	Interactive staircase that invites to take the stairs instead of elevator
	Workwalk (NL)	Route that facilitates walking meetings
P5	Roombeek area, Enschede ('streets to play') (NL)	Streets that are opened and closed for cars at certain times and jumping stones in pond
	Smartcity Living Lab Scheveningen (NL)	Smart sensors collect a variety of data, primarily for sustainability, but public health and vitality solutions are also considered
P6	Camping site	A kind of pleasurable troublemaking by giving up comfort and so creating circumstances where you need to move much more to do what needs to be done (like shopping, cooking, using the –often centrally located– facilities, but also play and entertainment)
	Theme park	People there walk considerable distances and spend a lot less time sitting down than on other days

P7	Skatepark, Steigereiland IJburg – Amsterdam (NL)	A busy area, attracting different age groups. Facilitates skating but also social bonding and walking routes
	Parcours	Training facility (for biking)
P8	Bike route, 'beautiful and free' (separate from car road)	
	(Inflatable) assault course	
	Schoolyard with 'challenging' playground equipment	
	Park 'n Play by JAJA Architects Copenhagen (DK)	
	Kwiek exercise route (NL)	Suggests exercises using objects already present in the area
	Geulberg area (NL)	Mountain bike trail and golf court on/around artificial hill (former dump site)
	Cruyffcourts	Public small soccer fields in residential areas
	Forest	In itself already a space for play and physical activity
P9	van Beuningenplein Amsterdam - by Carve (NL)	Multifunctional neighborhood area with pavilions and sport facilities
	Bicycle street	Street where bikes have preference
	Sport-axis Amsterdam (NL)	Bike and walking route
	Genneper Parken Eindhoven (NL)	
	Park Somerlust Amsterdam (NL)	Transition between urban and green area, both a transport and park place with attractive routes
	Gardens of Zandweerd in Deventer (NL) (under construction)	Cars stay at the edge of the neighborhood and streets have become garden paths
	Building where you see the stairs first and then the elevator	
P10	'Speeldernis' Rotterdam (NL)	Nature play areas
	Beweegtuinen e.g., Muiderwaard Alkmaar (NL)	Area with public fitness equipment, targeting senior citizens
	Passage Rijksmuseum (NL)	Infrastructure primarily for pedestrians and bikers
	Beuningenplein Amsterdam (NL)	
	Cruyffcourt	Especially when combined with neighborhood sport coach
	'Oegstgeester Ommetjes' (Strolls of Oegsteest) (NL)	Short walk routes with nature elements in residential area
	'Kindlint' ('Child-ribbon')	Dedicated child-safe low-traffic routes to important locations (e.g., school, playground, sport club)

	'Play streets' Roombeek Enschede (NL)	
	FIT happens (app)	App for active use of the public space (Rotterdam)
P11	Martikel no.8 – Copenhagen (DK)	
	Dynamic streets - example in Berada (PT)	The street is about facilitating mobility. What kind of mobility, and how we get from place to place is an important part of how physically active we are
	Multi sports installation – example in Matosinhos (PT)	
	Temporary use, multiple use; e.g., weekly rhythm & events – example: Art event in Zaragoza (ES)	
	Waterside (busy, lively) - example in Hoi An (VN)	
	Miera Street - Riga by Fine young urbanists (LV)	Street designed with priority for bikers and pedestrians, with shops and cafes, but with tram and car traffic in mind
	Areas for street play - example in Siena (IT)	

Curriculum Vitae

Loes van Renswouw was born on January 31, 1989, in Eindhoven. After obtaining her Gymnasium diploma from Bisschoppelijk College Weert in 2007, she studied Architecture, Building and Planning at Eindhoven University of technology. During her studies, she had a focus on building physics and building technology in her Bachelor program and on architecture in her Master's, from which she graduated in 2013. Her interest in creating healthy places already shows in her graduation project, which describes the transformation of a deserted office area into a 'healthy living environment'.

In 2014, she moved to Shanghai, China, to join the newly founded Shanghai team of Ellumus, an international design firm with a diverse scope of mostly large-scale architecture, urban, and interior design projects. As a project designer she was junior architect for different phases of diverse projects, with a focus on urban master planning and large-scale mixed-use retail.

Returning to Eindhoven, Loes started working at Fontys School of Sport Studies as a researcher in 2016, where she studied the value of user-generated big data for urban planning of active and healthy public spaces. Next to that, she also provided advice and support for housing associations to improve sustainability as a consultant and project manager at Atriensis.

In 2018, she continued her research at the Eindhoven University of technology faculty of Industrial Design, as a part of her PhD program in the Systemic Change group. Building on her earlier work, knowledge from the Industrial Design community, and her interest in the design and impact of healthy places, her PhD work –of which this thesis is the result– investigates how we can enhance the influential power of such places by integrating smart and interactive technologies, with a focus on encouraging physical activity in the urban public space. Next to her research, Loes has also been involved in education as a lecturer and project coach throughout her PhD project. She now continues educating next to her postdoc research projects about responsible AI solutions.

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2023

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Samenvatting

Door de jaren heen hebben technologische ontwikkelingen ons steeds meer comfort gebracht. De keerzijde van dit comfort is echter dat een groot deel van de bevolking steeds minder beweegt, met als gevolg verschillende nieuwe maatschappelijke problemen voor deze moderne samenleving. Regelmatige lichaamsbeweging is een bekend en belangrijk onderdeel van een gezonde levensstijl. Daarom vormen sedentair gedrag en lichamelijke inactiviteit een toenemend probleem voor de volksgezondheid. Design biedt in verschillende disciplines de mogelijkheid om mensen aan te moedigen, te overtuigen of zelfs te dwingen tot actiever gedrag. Voorbeelden hiervan zijn het ontwerpen van actieve stedelijke omgevingen en het gebruik van zogenaamde 'persuasive technologies' ('overtuigende technologie'), die beiden aanzienlijk kunnen bijdragen aan het stimuleren van actiever gedrag.

Het onderzoek dat wordt beschreven in dit proefschrift bouwt voort op kennis van het ontwerpen van actieve omgevingen, 'human-computer interaction' of HCI (de interactie tussen mens en computer), ontwerpen voor gedragsverandering en ontwerpen met data. Het doel van dit werk is het vergroten van het positieve effect van 'actieve omgevingen' door het toevoegen van interactieve technologieën. Hiervoor brengen we aspecten uit deze verschillende werkvelden samen die bijdragen aan fysieke activiteit en dit stimuleren. Daarom hebben we onderzocht hoe we kunnen ontwerpen voor actieve stedelijke omgevingen door het integreren van data en interactieve technologie in zowel het ontwerpproces als in de resulterende ontwerpoplossingen.

Deze uitdaging zijn we aangegaan door een aantal complementaire studies die worden beschreven in dit proefschrift. We verdelen deze studies hier in vier thema's: Actieve Omgevingen, Richting interActieve Omgevingen, Perspectieven op Data en een casus die inzichten van de voorgaande delen samenbrengt: Pathfinder.

Na een algemene introductie in hoofdstuk 1, beginnen we in het eerste deel met het onderzoeken van *Actieve Omgevingen*. Hier geven we een overzicht van bestaande kennis uit zowel onderzoek als de praktijk op het gebied van het ontwerpen en realiseren van actieve omgevingen. In hoofdstuk 2 bespreken we definities van actieve omgevingen en hun toegevoegde waarde om beweeggedrag te bevorderen. Ook geven we een overzicht van het spectrum van ontwerpstrategieën, elementen en randvoorwaarden die gebruikt worden om deze omgevingen te creëren. Daarnaast beschrijven we de typische stappen in het ontwerp- en realisatieproces, met daarbij de soorten stakeholders, belangrijkste tekortkomingen en knelpunten. We baseren ons hierbij op 11 interviews met experts en 51 voorbeelden van actieve omgevingen die zij aandroegen. Met dit werk geven we een overzicht van de impact van actieve omgevingen, de instrumenten en strategieën die gebruikt worden om ze te creëren en de uitdagingen die nog moeten worden aangepakt. Deze kennis vormt de basis voor de volgende stappen in ons onderzoek.

In het tweede deel gaan we verder *Richting InterActieve Omgevingen*. We verkennen hoe de integratie van data en (interactieve) technologie de positieve effecten van actieve omgevingen

kunnen versterken. Door schetsen, een benchmark van bestaande concepten en een analyse van ontworpen voorwerpen brengen we de verschillende interventieniveaus, interactievormen, gedragsveranderingsstrategieën en technologische mogelijkheden om dit soort interActieve omgevingen te ontwerpen (hoofdstuk 3) in kaart. Hieruit volgen kansen om de rijkheid van interactiemogelijkheden voor dit doel verder te verkennen. Deze vormen zowel een basis voor discussie als inspiratie voor verder onderzoek.

Een aantal van de concepten uit hoofdstuk 3 worden verder onderzocht door een reeks ontwerpverkenningen, in de vorm van casus studies. Met behulp van deze ontwerpen bestuderen we het gebruik en de effectiviteit van oplossingen die (1) motivatie en/of prestatie positief beïnvloeden door personalisatie, het stellen van doelen en het geven van feedback, door Guided by Lights – een adaptief lichtsysteem voor persoonlijke begeleiding in hoofdstuk 4; (2) fysieke activiteit aanmoedigen door de ervaring te verbeteren, door Sensation – een gesonificeerd hardlooppad in hoofdstuk 5; (3) bestaand beweeggedrag bevorderen, door Discov – een interactieve wandelervaring in hoofdstuk 6; en (4) fysieke activiteit en sociale verbinding stimuleren middels de multidimensionale aantrekkingskracht van water, door Fontana – een interactieve waterinstallatie in hoofdstuk 7. Deze diverse casussen demonstreren de potentie van interActieve omgevingen om door hun inclusieve en verleidende karakter fysieke activiteit te bevorderen. Tegelijkertijd brengen ze ook de uitdagingen naar voren die gepaard gaan met de transitie van tijdelijke, lokale installaties naar duurzame en schaalbare oplossingen.

In het derde deel bespreken we *Perspectieven op Data* gerelateerd aan dit onderzoek. We kijken hierbij naar hoe data gebruikt en bekeken wordt door de werkvelden van stedenbouw en HCI en hoe deze perspectieven elkaar kunnen versterken bij het ontwerpen voor interactieve omgevingen die zich op het snijvlak van deze velden bevinden. We beginnen in hoofdstuk 8 met het bestuderen van een grote, door gebruikers gegenereerde dataset van een hardloop-applicatie voor smartphones, die gegevens bevat over 1,5 miljoen hardloopsessies. Door een explorerende en iteratieve onderzoeksaanpak krijgen we inzicht in de relevantie van verschillende omgevingsfactoren voor geoptimaliseerde hardloopomgevingen.

Hierna onderzoeken we hoe dit soort 'user-generated big data' ontwerpers kan helpen in het vormgeven van meer beweegvriendelijke en adaptieve omgevingen door twee data-lenzen te introduceren in hoofdstuk 9: een collectieve en een individuele lens. Door exploratieve datavisualisaties van dezelfde hardloop-dataset gecombineerd met publieke databronnen en een workshop onderzoeken we hoe deze lenzen waardevolle inzichten kunnen geven voor stedenbouwkundigen en de HCI-gemeenschap en hen kunnen inspireren.

In het vierde en laatste deel sluiten we in hoofdstuk 10 af met *Pathfinder*, een uitgebreide casus waarmee we een alternatieve visie op interActieve omgevingen verkennen. Hier onderzoeken we hoe de uitdagingen met betrekking tot schaalbaarheid kunnen worden aangepakt en verdiepen we ons verder in het gebruik van 'big data' om dit soort oplossingen verder te brengen door middel van kunstmatige intelligentie. Hiervoor hebben we een breedvoerig prototype gemaakt en uitgerold in een studie met 18 deelnemers. Deze studie liet zien hoe gepersonaliseerde route-suggesties de beleving van de omgeving kunnen beïnvloeden en daardoor kunnen bijdragen aan het verbeteren van de beweegervaring. Met Pathfinder demonstreren we hoe interActieve omgevingen kunnen worden opgeschaald en hoe we door mensen door een gebied te leiden gepersonaliseerde omgevingservaringen kunnen creëren en daarmee hun beweegervaring kunnen verbeteren.

Door deze studies en de verschillende invalshoeken die we hebben belicht, hebben we het concept interActieve omgevingen verkend, onderzocht en beschouwd, net als hoe deze kunnen bijdragen aan het stimuleren en aanmoedigen van actievere leefstijlen. Dit levert verschillende bijdragen op aan zowel de theorie als praktijk van het ontwerpen van in de omgeving ingebedde en interactieve oplossingen om actief gedrag aan te sporen; we presenteren empirische nieuwe bevindingen en design artefacten. Daarnaast leveren we ook kleinere theoretische en methodologische bijdragen. In de algemene discussie (hoofdstuk 11) brengen we de conclusies van de verschillende studies samen om de onderzoeksvragen te beantwoorden. We reflecteren op onze bevindingen en hoe deze zich verhouden tot bestaand werk en ontlenen implicaties voor toekomstig onderzoek en werk in de praktijk.

Summary

Over the years, technology has provided us with ever increasing levels of comfort. The downside of these developments, however, is a considerable decrease in physical activity for a major part of the population, resulting in a new array of concerns for this modern society. Frequent physical activity is a well-known and key part of maintaining a healthy lifestyle, making sedentary behavior and physical inactivity an increasing public health concern. Design offers opportunities to encourage, persuade, or push people toward more active behavior in various disciplines. This includes the design of active urban environments and the use of persuasive technologies, which can contribute significantly to stimulating people to be more active.

The research described in this doctoral dissertation builds on knowledge from active environment design, human-computer interaction, design for behavior change, and design with data. Bringing together aspects from these fields that contribute to and encourage physical activity, the present work aims to increase the positive effect of active urban environments by designing and embedding interactive technologies in those spaces. We therefore researched how to design for active urban environments by integrating data and interactive technology in the design process and the resulting design solutions.

To address this research challenge, we conducted a set of complementary studies which we present in this thesis, divided into four parts: Active Environments, Toward interActive Environments, Perspectives on Data, and a case study that brings together insights from the previous parts: Pathfinder.

After a general introduction in chapter 1, we start by investigating *Active Environments* in the first part. Here, we outline existing knowledge from practice and research in the field of active environment design and realization. In chapter 2, we discuss definitions of active environments and their added value to encourage active behavior and provide an overview of the spectrum of design strategies, elements and boundaries used to create them, based on 11 expert interviews and 51 active environment examples they provided. We also describe typical steps in the design and realization process, including the types of stakeholders, main gaps, and points of friction. With this work, we provide an overview of the impact of active environments, the tools and strategies used to create them, and the challenges that still need addressing. This body of knowledge serves as a foundation for the next steps of our research.

In the second part, we move *Toward InterActive Environments*. We explore how the integration of data and (interactive) technology can enhance the positive effects of active environments. Through sketches, a benchmark of existing concepts and an analysis of designed artefacts, we map the different intervention levels, interaction modalities, behavior change strategies and technological opportunities to design such interActive environments (chapter 3). This results in opportunities to further explore the richness of interaction modalities for this purpose, forming a base for discussion and inspiration for further research.

Several of the derived concepts are investigated further through a series of design explorations, captured as case studies. Through these designs, we explore the use and effectiveness of solutions that (1) positively impact motivation and/or performance through personalization, goal setting, and feedback mechanisms, through *Guided by Lights – an adaptive light system for personal guidance* in chapter 4; (2) encourage more physical activity by improving the experience through *Sensation – a sonified running track* in chapter 5; (3) reinforce existing active behavior through *Discov – an interactive walking experience* in chapter 6; and (4) stimulate physical activity and social connectedness using the multidimensional attractiveness of water through *Fontana – an interactive water installation* in chapter 7. These variegated explorations demonstrate the potential of InterActive environments to encourage physical activity through their inclusive and persuasive nature, but also highlight challenges related to moving from temporary, local installations to sustainable and scalable solutions.

In the third part, we discuss *Perspectives on Data* related to this research. Here, we look more closely at how data is used and regarded in the fields of Urbanism and HCI and how these perspectives can be leveraged when designing for InterActive environments that exists at the intersection of these disciplines. We start in chapter 8 by studying a large user-generated dataset from a run-tracking smartphone application containing information of 1,5 million runs. Using an explorative and iterative research approach, we gain understanding in the relevance of several environmental factors for optimized running climates.

Next, we investigate how such user-generated big data can support designers in shaping more activity-friendly and adaptive environments by introducing two data lenses in chapter 9: a *collective* and an *individual* lens. Through exploratory data visualizations, using the same running dataset combined with public data sources, and a workshop, we investigate how these lenses can serve as sources of inspiration and yield meaningful insights for the urban design and HCI communities.

In the fourth and last part, we conclude in chapter 10 with *Pathfinder*, an extended case study that explores an alternative perspective on interActive environments, where we investigate how to address scalability challenges and further explore the use of big data to drive such solutions through AI. We built and deployed a high-fidelity prototype in a field study with 18 participants, which showed how personalized route suggestions could affect the perception of the environment and therefore contribute to improving the exercise experience. Through *Pathfinder*, we demonstrate how we can scale up interActive environments and create personalized environment experiences, effectively affecting the perception of existing environments by guiding people through them.

Through these multiple investigations and the different perspectives adopted, we explore, research, and reflect on the concept of interActive environments and how these can help in stimulating and encouraging more active lifestyles. This results in several contributions to both theory and practice of designing environmentally embedded and interactive solutions to encourage active behavior; we present *empirical* new findings and design *artifacts* and additionally make smaller *theoretical* and *methodological* contributions. In the general discussion (chapter 11), we bring together the conclusions of the studies to answer the research questions. We reflect on our findings, how these are situated in the related work, and derive implications for future research work in the field.

Over the years, technology has provided us with ever increasing levels of comfort. The downside of these developments, however, is a considerable decrease in physical activity for a major part of the population, resulting in a new array of concerns for this modern society. Frequent physical activity is a well-known and key part of maintaining a healthy lifestyle, making sedentary behavior and physical inactivity an increasing public health concern. Design offers opportunities to encourage, persuade, or push people toward more active behavior in various disciplines. This includes the design of active urban environments and the use of persuasive technologies, which can contribute significantly to stimulating people to be more active.

The research described in this doctoral dissertation builds on knowledge from active environment design, human-computer interaction, design for behavior change, and design with data. Bringing together aspects from these fields that contribute to and encourage physical activity, the presented work aims to increase the positive effects of active urban environments by designing and embedding interactive technologies in those spaces. Through a set of complementary studies and adopting different perspectives, we investigated how to design for such 'interActive' urban environments by integrating data and interactive technology in the design process and the resulting design solutions. With this work, we explore, research, and reflect on the concept of interActive environments and how these can help in stimulating and encouraging more active lifestyles.