Sonic City: The Urban Environment as a Musical Interface

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ABSTRACT
In the project Sonic City, we have developed a system that enables users to create electronic music in real time by walking through and interacting with the urban environment. We explore the use of public space and everyday behaviours for creative purposes, in particular the city as an interface and mobility as an interaction model for electronic music making. A multi-disciplinary design process resulted in the implementation of a wearable, context-aware prototype. The system produces music by retrieving information about context and user action and mapping it to real-time processing of urban sounds. Potentials, constraints, and implications of this type of music creation are discussed.

Keywords
Interactive music, interaction design, urban environment, wearable computing, context-awareness, mobility

1. INTRODUCTION
Sonic City is a novel interface for musical expression through interplay with the urban environment. Unlike the majority of work in this domain, which tends to focus on concert-based performance, this project promotes musical creativity integrated into everyday life, familiar places and natural behaviours [19].

We describe the development and first implementation of a wearable system that creates electronic music in real time, based on sensing bodily and environmental parameters. Context and user action are mapped to sound processing parameters and turn live concrete sounds into music. Thus, a personal soundscape is co-produced by a user's body and the local environment simply by walking through the city. Considering the city as an interface and mobility as musical interaction, everyday experiences become an aesthetic practice. Encounters, events, architecture, weather, gesture, (mis)behaviours – all become means of interacting with, appropriating, or 'playing the city'.

In this paper, we first introduce our approach to the city and musical interaction. We then outline the development process together with design methods and issues and describe the resulting implementation of a first prototype. Finally, we reflect on the project and discuss potentials and constraints inherent in the system and this type of music creation.

Figure 1: Sonic City enables users to interactively create music by walking through a city

2. THE CITY AS INTERFACE
The city has long been an inspiration and site for musical expression, whether as a metaphor in classical composition, a source of rhythms and sounds in jazz and electronic music, a stage for street performance or the cradle of a walkman generation. Music is inextricable from the lifestyles and textures of daily urban life. It is also an accessible and well-established form of public aesthetic expression available to everyone. Indeed, making or playing music has been a means of re-appropriating public space for localised concerns, whether as community expression or even as a form of protest (e.g. [22]). Therefore, we believe that the city offers tremendous possibility for personal musical expression and creativity.

Everyday urban experience involves active interpretation and impels creative response – consider the meaning of a screeching noise, the smell of burning rubber and a car headed your way! As a 'physical interface', the city provides a built infrastructure and established ways of using it creatively. Even the mundane act of taking a walk involves the complex co-production of bodily movement in relation to obstacles. Along the way, there are always elements of serendipity: an unexpected view, surprising encounters or fleeting ambiances. Built and transient conditions require continual tactical choices and inspire possibilities along the way. Whether a pleasant stroll or a mundane commute, being in the city involves dynamic creative improvisation.

Use of the physical city is conditioned by our own perceptions, habits, histories, and emotions. Terms such as *mental map* and *psycho-geography* in urban theory describe the special image of the city we each have, characterised by informal landmarks, subjective distances and sizes, and intuitive way-finding (e.g. [1], [13]). Activities such as skateboarding and parkour exemplify the highly personal ways in which we perceive and use the city, in this case physical or acoustic appropriation of the built environment for personal expression [2, 18]. The built, narrative, and emotional landscape of the city is an established topic in everyday as well as aesthetic practices such as performance and sound art, and soundscape composition [25].

In this project, we take the simple act of walking to explore the city as an interface and opportunity for personal creativity. Everyday behaviours, personal (mis)uses, and aesthetic practices suggest the inventive ways in which people already use the physical city. As a new platform for personal expression and urban experience, Sonic City explores public space as a site for private performances and emerging behaviours, and the city as an interface for personal musical expression.

3. MOBILITY AS INTERACTION

Urban environments are often places of transit, where people are constantly mobile. They adopt appropriate behaviours for public situations, use portable technologies, navigate and make decisions on the fly. Being in the city implies a dynamic shifting among heterogeneous contexts and behaviours. This, and recent developments in mobile and context-aware computing, prompted us to consider the use of mobility itself as a means of interaction in electronic music making. We see mobility in the city as a large-scale version of gesture-based interaction combined with context-awareness, which can be exploited for music creation.

3.1 Gesture and Context

Gesture is generally defined as “a specific movement from part of the body, executed or not in a conscious way, applied or not to a device, that can accompany a discourse or have a meaning by itself” [24], leading – in the context of musical interface research – to the musical output of an interactive system. A large amount of work has been done in the field of electronic music and dance technology (e.g. [11, 23]).

Context-awareness has been defined as the ability of a device or application to “adapt according to its location of use, the collection of nearby people and objects, as well as changes to those objects over time” [20] or to “monitor changes in the environment and adapt [its] operation according to predefined or user-defined guidelines” [9]. Primarily applied human-computer interaction, mobile and ubiquitous computing, this property can also be used to output music: in ATR’s Sensor-Doll project [26], the musical results of a user’s interaction with a doll differs depending on context.

3.2 Mobility

From our point of view, mobility can be seen as physical movement extended spatially, over time, and through multiple contexts. This is exemplified in the simple act of walking through the city as a sequence of contexts experienced over time and shaped by dynamic urban conditions and personal choices of route.

If we consider the act of walking in the same way as we do gesture – as a deliberate and creative action – then the movement of a pedestrian through the surrounding environment can be modelled as a combination of gesture-based interaction and context-awareness. Rather than applying both of these in parallel, we are applying a model that correlates them (see Figure 2), such that it is the interaction between the user and the city that generates music.

gesture user action → output

context-awareness context → output

vs.

mobility user action + context → output

Figure 2: Mobility as interaction

4. RELATED WORK

Sonic City is related to other projects dealing with urban settings and sound or musical expression. Projects involving the city in interaction include the *Citywide Performance* project [6], an urban mixed-reality game event, and *Sound Mapping* [16], a site-specific outdoor interactive music event with portable sensor-based devices. The *Touring Machine* [8] uses location-awareness to supplement real space with a virtual information overlay. *Pirates!* [3] uses proximity and location in real space as interaction elements in virtual game play. *Noiseman* [7], *Sonic Interface* [14] and *Nomadic Audio* [15] propose new interactions with urban sound: Noiseman and Sonic Interface filter and mix urban sounds on the move, and Nomadic Audio creates a dynamic soundscape from local radio frequencies. *CosTune* [17], a networked wearable musical instrument, and *Sensor-Doll* [26] have been developed by ATR for communicative and social purposes.

The goals of Sonic City vary from these projects in terms of expressive genre, sound qualities, and interaction due to differences in intention and research questions. Sonic City belongs to neither a performance, game or communication genre, focussing instead on personal expression and everyday creative use of public space. In this way, it differs from the aforementioned projects of ATR that use music to support social communication and the gaming examples that specify rules, goals, and duration of the experience. Where the focus of the Sound Mapping project is on a performance event, taking place within a restricted area, Sonic City is meant for everyday use by anyone, anywhere.

Sonically, our project is greatly inspired by soundscape composition [25]. However, where this relies on pre-recorded sounds (as most sound-based projects mentioned above) and is listened to out-of-context, sound content in Sonic City is linked directly to the physical location where it is being produced and heard. Urban sounds are transformed into a real-time personal soundscape, as an overlay to the actual acoustic surroundings.

In terms of interaction, music in Sonic City is co-produced by both the listener and the city. Citywide Performance, Costune and Touring Machine projects treat the city is a setting for rather than a participant in interaction. In Noiseman, Sonic Interface and Nomadic Audio, a listener interacts with the urban soundscape using a tangible or visual interface on a handheld device. In Sonic City, conditions of the body and the environment contribute jointly to music creation, shifting the focus to the city itself as an interface and direct physical engagement with the city as interaction.

5. DESIGN PROCESS & DEVELOPMENT

The goal of Sonic City is to provide a mobile musical experience for a wide range of users in a variety of urban environments. Thus, the system developed in the project needs to be location-independent and robust enough to be used outdoors and on a daily basis. Rather than relying on a fixed infrastructure, such as sensors deployed in the environment, we opted for an entirely wearable solution in order to support user mobility. Starting with these premises, we then explored a variety of possibilities for what Sonic City could be like.

Essential questions we dealt with were:

- What from the user and the city would be interesting as input?
- How should the music sound?
- What is the amount and nature of user control?
- How should inputs be mapped to music output?

In order to address these and to gain insight in an ongoing manner from users and relevant experts, we have applied a multi-disciplinary and iterative development process. Backgrounds of core team-members include engineering, interaction design and architecture. During the project, we have collaborated with a sound artist, a sociologist, a product designer, and a cognitive scientist. User-centred design methods such as ethnographic studies, scenarios, and workshops have provided insight into the user experience, enabling us to develop a system and sounds that would be interesting for extended use and a wide range of musical expertise.

5.1 Input Parameters

In order to determine interesting input parameters, we re-examined characteristics of walking in the city and carried out some limited ethnographic studies. We conducted stationary observations of specific sites and documented paths of pedestrians with action logs (see Figure 3). This gave us insight into relevant and interesting aspects to sense and helped to imagine sequences of actions, events and ambiances along a walk as a potential composition. Observations of specific sites uncovered essential patterns of action, for example behavioural sequences at crosswalks (e.g. glancing, changing course and speeds). Obstacles such as stairways were interesting conjunctions of fixed and mobile elements, including structural elements (step patterns and railings) and pedestrian behaviour (styles of climbing stairs, congestion, and turn-taking).

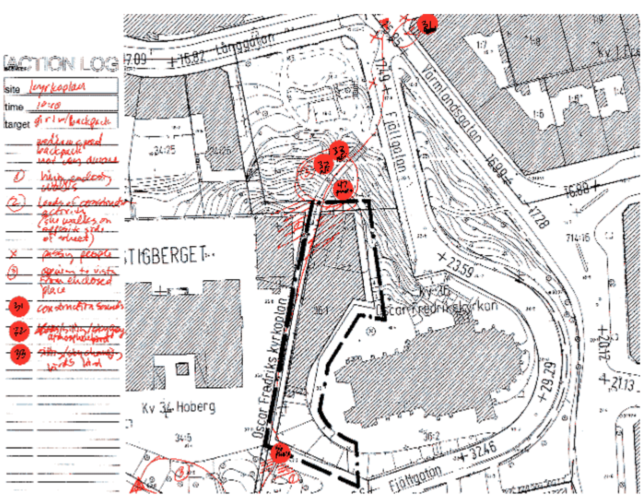

Figure 3: Example of an action log

From the observations, characteristics of pedestrians and surroundings were categorised in terms of action and context. High-level descriptions, such as ‘indoors’ and ‘crossing the street’, were broken down into measurable cues that the system could use for context and action recognition. From this, possible input parameters from sensors emerged:

- *Body-related input:* heart rate, arm motion, speed, pace, compass heading, ascension/descent, proximity to others/objects, stopping and starting
- *Environment-related input:* light level, noise level, pollution level, temperature, electromagnetic activity, enclosure, slope, presence of metal

Some types of input involved a range of continuous values fluctuating over time, e.g. the outside temperature or a pedestrian’s heart rate. Other types, for instance a car horn, only occurred momentarily, in a way that could be described as discrete (see Table 1).

This gave us a framework for making decisions about sensing and retrieval in Sonic City. In terms of choosing sensors, some seemed more relevant than others when confronted with the opinion of potential users and were therefore prioritised in the implementation phase.

Table 1. Characteristics of low-level input parameters

	Body	**Environment**
Discrete factors	sudden change in user action (ex: stopping)	localised events (ex: a car passing)
Continuous factors	physiological state (ex: heart rate) actions over time (ex: compass heading)	evident ambiances (ex: level of light) invisible ambiances (ex: pollution level)

5.2 Sound Design

The sound design needed to be consistent with how people already perceive and experience the environment of the city. With this in mind, we worked with a sociologist (Magnus Johansson) to develop hypothetical scenarios of user experiences, values, and taste. The scenarios were based on potential users that we knew or interviewed. They were deliberately extreme in order to represent a wide range of possibilities and design implications. Besides helping to determine the amount and nature of user control supported by the system (see the paragraph on control), they revealed differing personal relationships with the city. Specifically, we considered peripheral versus foreground aspects of the experience and musical possibilities ranging from ambient to rhythmical. Based on the scenarios, we defined the boundaries of the sound design space (see Figure 4).

We were interested in maintaining a close experiential relationship between the sound content and the context of music creation – namely the existing city soundscape. Thus, we decided to use real-time audio processing of urban sounds as a basis for the sound design. In order to develop interesting sound content from an artistic point of view, we have been working in close collaboration with the sound artist Daniel Skoglund of 8tunnel2 [27], and have been inspired by the musical genres of soundscape composition [25] and glitch [5]. Designed possibilities cover all four quadrants of the design space.

Interesting processing parameters emerging from the sound design process were abstracted according to the kind of musical impact they would have on the output. They were classified into:

- *Structural composition variables,* relative to the number of sound layers and the temporal structure of the music (f. ex., if making an analogy with pop music, a change from a couplet to a chorus)
- *Spectral variables,* which determine the quality of each sound (their timbre, envelope, etc.)
- *Triggering* of short musical events

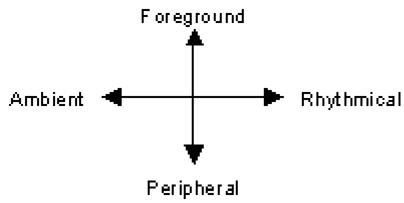

Figure 4: Sound design space

5.3 Control

When considering questions of user perception and control over the music, we asked ourselves how 'in charge' of the experience a user should feel:

- Should there be means for *explicit control* over the sound, such as buttons, in case a user would not obtain the desired music just through interaction with the city?
- What degree of *randomness* could be built in the system to maintain interest? In situations of unvarying sensor input values over long periods of time, should the music remain exactly the same? For everyday use of Sonic City, how similar could the same walk sound day after day without becoming boring?
- What should the *balance* be between the influence of user and environmental factors? How would 'invisible' factors (whether sensor-based such as pollution or processing-based such as randomness) be perceived?

The same scenarios of use as those mentioned in the preceding section were used to explore potential design directions. Then, we were able to define a control space (see Figure 5) that described the territory of possibilities and located the scenarios in relation to one another.

Two axes describe the predominant factors influencing the music. The vertical axis shows the balance of body or user input versus environmental or city input. To illustrate, *Jonas* is a sound engineer and thinks about music in a highly structured and systematic way. He would want a high degree of control over the music and its sound qualities and even be able to add or customise means of input. *Agnes*, in contrast, would only want the system to monitor tiny variations in the environment and is not interested in controlling the sounds herself.

The horizontal axis describes the span of possibilities from unpredictability to user-deterministic control. To illustrate, *Maria* roams the streets of her city at night as a form of escape. She does not go far and often takes the same path, but would want the music to modulate dramatically and vary each time, implying the introduction of randomness on system level. *Jean*, on the other hand, is a participant in the extreme sport of climbing urban structures. Each climb is like a conquest and happens only once. He would use Sonic City to monitor his body's engagement with each unique environment in a very direct way.

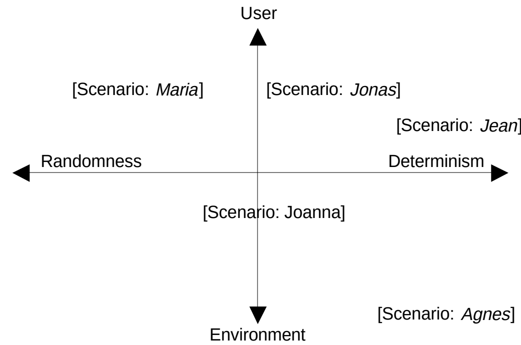

Figure 5: Control space with user scenarios

The scenario that we chose to implement was *Joanna*. Balancing both active engagement and urban discovery, Joanna would use Sonic City to re-discover her environment as a poetic and aesthetic practice. Representing the essence of our intentions with Sonic City, this scenario provides a foundation for testing other variables and possible experiences and is reflected in the mapping strategy.

5.4 Mapping Strategy

The mapping had to be both transparent to the user and complex enough to sustain interest if the system were to be used day after day. In our process, we took a top-down approach to mapping, starting with the essential concept of context. It has an intrinsically layered nature since a context can consist of several different levels of abstraction. This led us to the development of a layered mapping strategy similar to the "multiple layers" model [10]. In that model, input and output are each abstracted on a high level and are then linked together by a straightforward one-to-one mapping, while the low-level parameters that constitute these abstractions are actually cross-coupled.

We considered it essential that the mapping would reflect scales of time and distances covered while walking in the city and maintain the distinction between continuity and discreteness. Using the categories and abstractions of input and output described in previous sections, we developed the following mapping. The *high-level* abstraction of context and actions is mapped to structural composition parameters. The *low-level* discrete and continuous factors that make up the abstractions are also mapped directly according to their discreteness versus continuity, thus discrete factors trigger short musical events and continuous factors are mapped to spectral variables (see Figure 6). Within this general framework, decisions about details of the mapping were carefully made one at a time to insure coherence and pertinence.

We determined that the time it takes to go two steps (one pace) was a good updating period for context-recognition. If the tempo follows a user's steps, then the length of this pattern of action is comparable to that of half a bar, and structural composition variables reflect the natural rhythm of a walk. At the context and action recognition level, only changes lasting longer than this period of time are considered significant enough to be taken into account by the algorithms, differentiating, for example, a general rise in noise level from temporary noises such as car horns.

Generally speaking, an input value can affect both layers of abstraction (for instance, lighting intensity is a continuous factor that also impacts context), and its effect on the output depends on its length in relation to an update period. Many of the low-level sound processing parameters also belong to more than one abstraction. Therefore, as in the "multiple layers" strategy, values are highly cross-coupled and the mapping is fairly complex, which we hope will sustain interest.

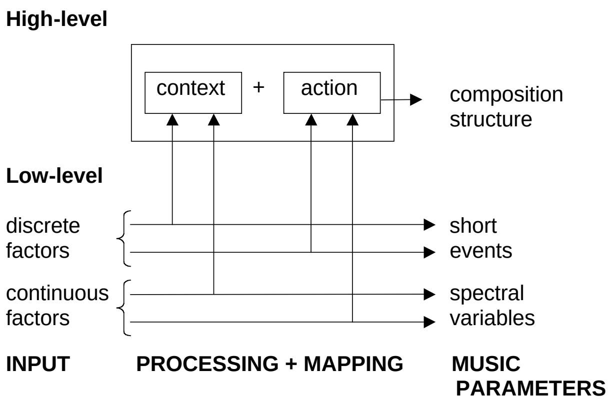

Figure 6: Mapping strategy

6. PROTOTYPE IMPLEMENTATION

We have implemented a prototype as a platform for iterative development and testing with users. For the sake of simplicity, only the most illustrative aspects of the design have been included in this current version. The prototype employs inexpensive and widely available components.

6.1 System Overview

The prototype consists of a set of environmental and biometric sensors, a BasicX-24 micro-controller, a USB-MIDI converter, a small laptop running the interactive music programming environment PD, a stereo microphone, and headphones (see Figure 7).

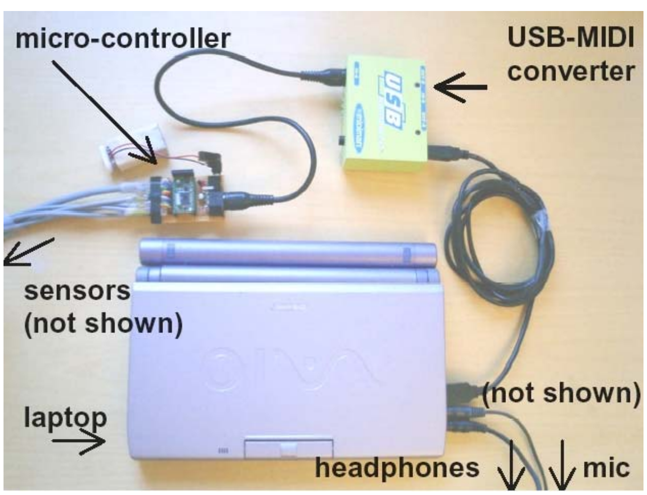

Figure 7: Components of the prototype

Sensor data is collected by the micro-controller and sent in MIDI format via the converter to the laptop. It is then converted and processed for context and action recognition. Resulting interaction parameters are mapped to musical parameters that shape the real-time audio processing of urban sounds captured by the microphone (see Figure 8).

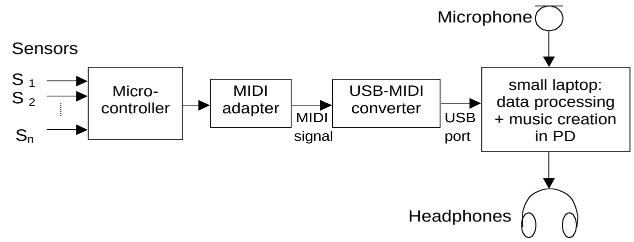

Figure 8: Dataflow

The hardware resides within the clothing worn on the user's body. Music is output through semi-open headphones, allowing the user to also hear the real environmental sounds, thus blending together both personal and existing soundscapes. For testing purposes, we have designed a one-size-fits-all adjustable jacket that incorporates all components of the prototype. While this is not a proposal for the final wearable, it allows for easy testing of sensor placement and orientations with multiple users in the city (see Figure 9).

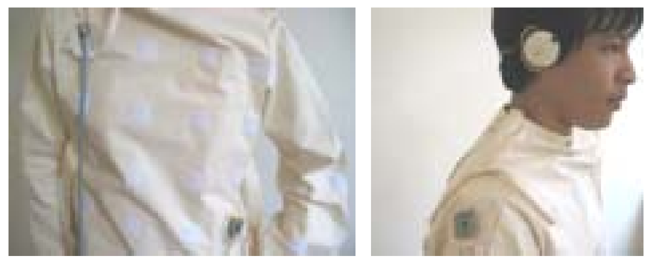

Figure 9: Testing jacket. Left: multiple sensor placement options; Right: user wearing headphones and sensor

6.2 Sensing and Retrieval

The sensors currently included are: a light-to-frequency converter, a sound gate, a metal detector, an accelerometer, a temperature sensor, and a pollution sensor. Two switch-buttons and a potentiometer knob are also included to support explicit interactions with the system, such as on/off. More sensors, measuring heart rate, ultrasound, electromagnetic activity, and atmospheric pressure, will be added later. Since each sensor affects multiple levels in the mapping, each interaction category currently has between three and six corresponding input possibilities.

The parameters that are identified and mapped to musical parameters in the current prototype are:

- *Contexts:* day vs. night, loud vs. quiet, cold vs. hot weather
- *Actions:* walking straight, left, right, running down stairs, standing still, pace
- *Continuous factors:* temperature, pollution level, lighting conditions
- *Discrete factors:* presence of metal, instantaneous noise level, jumps, steps, stops, starts

Context and action are retrieved inside the PD program, with "if-then" structured recognition algorithms. It is updated for every two steps made by the user.

6.3 Sound Processing

The output is shaped in real-time by sound processing objects such as filters, delay loops, envelopes, sampling, playback, mute, and echoes. The audio input can take manifold parallel and serial paths through these objects and can be deviated and redirected to other objects in a flexible way, which allows for a wide variety of output.

Structural composition variables consist of possible paths for the sound input through temporal processing (e.g. delays), the activation of processing channels, and the overall tempo. Spectral variables are determined by filters and feedback loops. Examples of possible triggered events include doubling the tempo, muting the rhythm, or triggering a sample.

6.4 Mapping

Input and sound parameters are mapped according to the layered strategy described in the design section. The following aspects have been implemented:

- The light intensity (continuous factor) currently determines the cut-off frequency (spectral variable) of filters that are opened and closed rhythmically. When walking under a shadow for a long time (context), this intensity also begins to influence the Q-value (spectral) of these filters.
- On top of a beat with the same tempo (structural variables) as the user's pace (action), layers of rhythm with tempos that are multiples of that of the first layer are triggered (musical event) when the sound input level is over certain thresholds (discrete factor). The dynamics of noises in urban settings can make the rhythm sound very organic. In a generally loud environment (context), the tempo is twice as fast (structure) as in a quiet context.
- If the user stops walking briefly (discrete), the rhythm is muted just as quickly (event), and if this stop lasts longer than the duration of the preceding two steps (action), everything is muted. The system requires active walking to function.
- Sudden proximity to metal (discrete) triggers filtered echoes (musical event), the delay of which (spectral) depends on the pollution level (continuous).
- At night (context), filtered (spectral) samples recorded randomly are played back and echoed (musical event) when sudden flashes of light (discrete), such as streetlights, are sensed.

We are also in the process of implementing an overall compositional structuring of the music based on metaphors of record spinning practiced by DJs.

7. DISCUSSION

7.1 The City as Interface

When reflecting on how we thought of the city in the project, what emerges is not only how we see the city as a means to an end – an interface to create music – but also as an end in itself. As an interface, the city is both a setting and the means of music creation. Fixed and fluid conditions in the city (for instance, architectural elements and traffic flows) structure user mobility. Perception of these is accomplished by the system through the range of sensors and formulation of input parameters. Thus, the city is a means for a user to interface with and control music creation – 'playing' the city as a musical instrument. Context parameters and urban sounds are necessary inputs to the system – the city not only enables music creation but music creation cannot happen without the city. In these ways, the system leverages existing urban experience to produce a new one. Our hope is that Sonic City not only encourages personal soundscape creation but also enhances perceptions of the city and possibilities for urban discovery.

7.2 Mobility as Interaction

In exploring mobility as a technique for interaction, we designed and implemented a mapping in which user action and context are combined rather than treated in parallel, and low-level city and user input is cross-coupled with sound parameters. Thus, we argue that we have achieved a successful interweaving of user action and context, which is intrinsic to our mobility model. In this respect, Sonic City approaches gestural interaction in a novel way. Mobility as interaction should promote natural behaviours and existing mobile lifestyles as sources of new creativity in everyday life.

7.3 Musical Expression

The sound design and mapping reflect our approach to personal musical expression in Sonic City. Besides achieving a close experiential link between the music and the existing soundscape, opting for real-time sound processing ensures an experience of use that will be continually evolving since the sounds around us are always different. Considering that every person has his or her own idiosyncratic behaviours and favourite routes, this means that the musical experience will always be personally expressive and responsive to our situations and choices. Along with carefully crafting the sounds with a sound artist, we hope that these choices will help to achieve ongoing interest in the music itself and a satisfying experience day after day.

8. CONCLUSIONS & FUTURE WORK

We have described the *Sonic City* project, which involves the multi-disciplinary design and implementation of a wearable system for music creation that treats the urban environment as an interface and mobility as interaction. Sonic City supports personal expression and transforms everyday behaviours into creative practice through natural and playful means of interacting with the urban environment.

Our next step will be to evaluate different aspects of the project. With the current prototype, we are able to test technical aspects in context and determine short-term user experience (e.g. musical satisfaction, choice of sensors, sense of control). In addition to the one we have had to date, future user workshops will continue to help us evaluate conceptual aspects and address lifestyle and aesthetic questions. We believe that having both a prototype and illustrative scenarios of use is necessary to make the project less abstract for people who are encountering this type of interactive technology for the first time. Based on the feedback we will be collecting in the next 2 months, we will draw conclusions and derive implications for refining the prototype.

However, for testing aspects of everyday, long-term use and misuse, the current prototype is too limited. It has too many wires and hardware components to carry around, a noticeable latency in sound processing and control, and is not modular or robust enough. Therefore, we plan to develop a new prototype, which will also incorporate additional functionality. We are considering switching to the *Smart-Its* platform [20]. Smart-Its are wireless, small-scale computing devices with built-in sensors, computation, and ad-hoc network communication. They are thus modular enough to be re-combinable by the user, and they enable distributed computing of context and action recognition at the device network level, leaving sound processing as the only task to be performed by the computer (preferably hand-held). Once this next prototype implemented, we will use cognitive science methods [12] to evaluate aspects of way-finding behaviours, long-term satisfaction, evolution of skill, emerging behaviours, and how Sonic City could fit into everyday lifestyles of city dwellers.

9. ACKNOWLEDGMENTS
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