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Aspects of Ambient UX Design Within Design-to-Robotic-Production and -Operation Processes

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Abstract. Ambient User Experience design in architecture implies consideration of various intersecting and sometimes overlapping design fields such as interaction and architectural design with the aim to achieve a continuous and cohesive user experience across devices, time, and space. In this paper, Ambient User Experience design is explored in relation to Design-to-Robotic-Production and -Operation processes developed at TU Delft, which link computational design with robotic production and operation. Several case studies involving the integration of sensor-actuators into the built environment are discussed with respect to mapping activities through constraints and enablers and designing with the time as a variable.

Keywords: Ambient User Experience · Design Domains · Interaction design · Architecture design · Design-to-Robotic-Production and -Operation

1 Ambient User Experience

The diffusion of digital technologies imposes an upgrade of design knowledge and skills, and, between others, of drawing capabilities. The design of digitized services that enhance activities within functional physical spaces requires the integration of multiple design competences: service, communication, interaction, product and architectural design. Furthermore, the design of technology-based solutions, requires the collaboration between experts of different disciplines, such as engineers and business managers, and their involvement in co-design processes. In order to manage the complexity of these physical/digital solutions, and to ensure a design result oriented towards the optimal satisfaction of users, new design approaches and mapping techniques focused on experience and on user activities are needed [1, 2].

Ambient User Experience (UX) aims to provide a continuous and cohesive user experience across devices, time, and space. The design of Ambient UX involves various intersecting and sometimes overlapping design fields such as interaction and architectural

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design that have subdomains such as design, human–computer interaction, software development, etc.

Ambient UX is a conceptual framework that provides a strategy for structured design processes that target Cyber-Physical Systems (CPSs) [3]. The Ambient UX framework consists of a definition of Design Domains (DDs) (what is to be designed) and User Values (why it is designed) observed within Ambient UX and CPS [4]. Ambient UX design in architecture implies consideration of various intersecting and sometimes overlapping DDs such as interaction and architectural design with the aim to achieve a continuous and cohesive user experience across devices, time, and space. In projects focused on user experience, design activities are not only aimed at defining the physical characteristics of spaces, but also at representing users' physical and cognitive activities in time, and the interactive processes. The overall design integrates the design of interactions with the design of physical environments. In this context, mapping out users' activities through use-case scenarios is considered. From the natural constraints i.e. physical constraints that limit what can be done to the affordances, which convey possible uses, actions, and functions [5], a palette of constraints and enablers is identified. These constraining/enabling points of activities are starting points for designing user experiences.

Fig. 1. Analysing social activities and speculating on new activities within the urban environment.

2 Design Domains

2.1 Mapping Activities Through Constraints and Enablers

Developing design strategies in experience-centred design requires thorough understanding of the users, their goals, motivations and thought-processes, guided by emotional states and contexts. An experience can be observed as an episode, a story within a certain time length, that emerges from the dialogue of a person with the surrounding world through actions [6]. Designing for everyday activities from the perspective of perceived experience through emotions, rather than from the perspective of material output, opens up many possibilities for reflecting on meaningfulness in design scenarios [7]. Such an "an experience" can be seen as a particular meaningful momentary construction [8], with a beginning and an end, that grows from the interaction between people and their environment.

For all the maps, as experience design tools, is common that they are activity-based designs [1, 9]. People are always in an environment that consists of contexts and technologies, in which they are engaged in activities [10]. The activities are enabled within an ecosystem relying on interactions between organisms, and between those organisms and their environment, which together create an ecology that is greater than the sum of its parts [11].

In this context, mapping out users' activities through use-case scenarios is considered. From the natural constraints i.e. physical constraints that limit what can be done to the affordances, which convey possible uses, actions, and functions, a palette of constraints and enablers is identified. These constraining/enabling points of activities are starting points for designing user experiences.

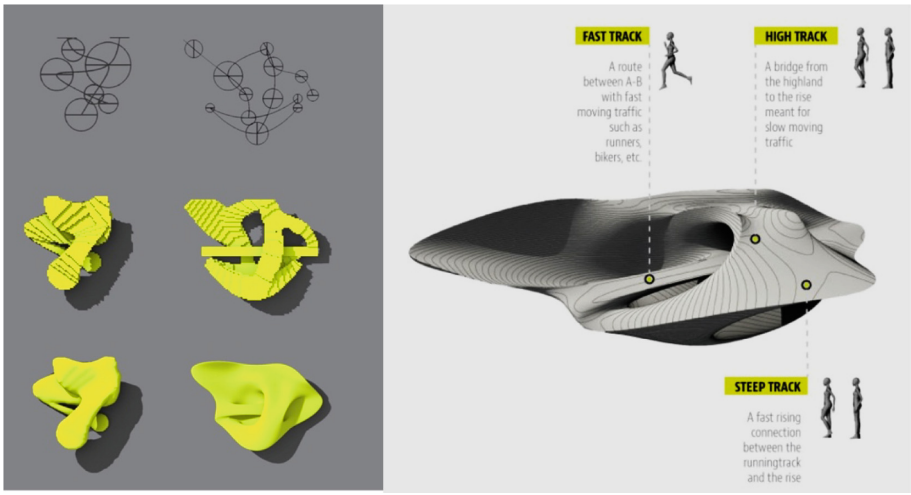

Fig. 2. Mapping out diverse types of activities and routes that the physical shape facilitates.

2.2 Three Architectures with the Time as a Variable

In order to identify Design Domains (DD) for Ambient UX an investigation into cases studies is implemented. The samples of cases were gathered from a course on interactive architecture, that is offered at Robotic Building (RB) (formerly known as Hyperbody), Technical University Delft. Within the design studio course on Design-to-Robotic-Production and =Operation (D2RP&O) for Interactive Urban Furniture [12], Master students were encouraged to represent experiences in architecture by merging physical and digital design aspects and projecting perception and experience of the users. Students developed projects in phases such as analysing the context, defining the concept, developing the project on macro, meso and micro scales, and finally arriving to a tangible prototype of a parametrically defined architectural structure. From analysing and mapping activities, to understanding the needs and developing the concept design, the

students defined the physical form while integrating interactive components that support diverse services such as adaptive lighting, sun shading, etc.

In terms of interaction, the emphasis was put on the user-centred approach: When proposing a design concept, students were focusing on the experience of the people that would use the space, and the perceptions of the context of use itself. Mapping activities enabled identification of three networks of interactions with three diverse architectures, where time is a variable: spatial (interaction related to the physical environment), information (interaction related to information flows), and relational (interaction related to human/social relations).

Spatial Architecture by Means of D2RP&O. Spatial architecture, as one of the DDs for Ambient UX, relies on the traditional comprehension of architecture as physically built environment relying on spatial and product/artefact design that finds its roots in the practice and teaching established within the Bauhaus, school of design, architecture, and applied arts. Somewhat similarly to Gropius [13] identifying that the New Architecture is the product of the intellectual, social and technical conditions of its age and time instead of relying on the morphology of dead styles, RB studio explores the potential of new technologies such as robotics. Design is implied as intervention on diverse scales, from an environment to building components and individual artefacts/products.

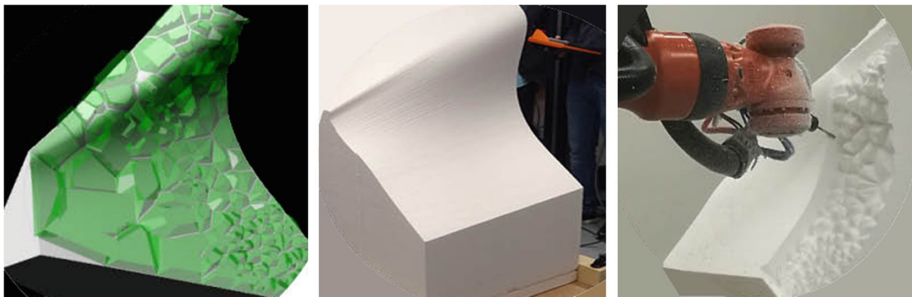

Fig. 3. D2RP process linking parametric 3D model (left) with robotic hot wire cutting (middle) and milling (right).

Architecture as an Ambient UX DD involves design and manufacturing of physically built environments that adapt to human needs. D2RP&O is a particular approach developed at TU Delft [14] that facilitate the integration of advanced computational design with robotic techniques in order to produce performative architectural formations (Fig. 1 and 2). Performances considered are inter al. functional, structural, environmental, and operational.

D2RP&O links design and production with smart operation of the built environment and advances applications in performance optimization, robotic manufacturing, and user-driven operation in architecture. It is relying on human and non-human interaction in the design, production, and operation of buildings. It is fundamentally changing the role of the architect. Architects design increasingly processes not artefacts/buildings, while users operate multiple time-based architectural configurations emerging from the

same physical space that reconfigures in accordance to environmental and user specific needs. In this context, D2RP&O empowers architects to regain control over the design implementation into physically built environments and allows end-users to participate as co-creators in the adaptation i.e. customization of their environments over time.

For developing the spatial architecture, students start by mapping the moments and positions of planned and/or predicted activities to take part using simulation tools (Fig. 2). The spatial design is then iteratively defined by taking functional, structural, environmental, materialization, and operational requirements into consideration. While functional requirements refer to use, structural and environmental performances ensure stability and comfort of the structure. Furthermore, materialization requirements involve material properties, production and tools requirements, while operational aspects involve sensor-actuators ensuring responsive and/or interactive behaviours. The D2RP&O approach ensures that the 3D model is linked with robotic production and operation (Fig. 3).

Robotic operation involves sensor-actuators embedded into the built environment and responding to and/or interacting with people. It is relying on information architecture.

Information Architecture. Information architecture, as one of the DDs for Ambient UX, involves management of information [15] and involves patterns and sequences of interaction.

Fig. 4. Design scheme for a dynamically responsive lighting system based on automated inputs was linked real-time to user activities such as seating, walking, running.

In order to develop such patterns, students define the desired interactions enabled by systems of sensors and actuators, such as for example a dynamic change of lighting through intensity and colour, according to the movement of the users within the physical structure and the social moments and settings (Fig. 4 and 5). When shaping inputs and outputs and the information flows, enablers are defined through triggers of pre-designed responses to them, while constraints reflect the fact that only certain triggers and pre-designed responses are selected while all the other possibilities are disabled. Information architecture is visible to the users only when being present within the designated spatial areas and when the triggers for dynamic changes are performed.

The focus of the information architecture in the RB studio 2017 was on light. The dynamically responsive lighting system was linked real-time to user presence and activities such as seating, walking, running (Fig. 4 and 5). Light colour, intensity, turn on-off patterns were correlated to the number of people present as well as the static or dynamic use of space. Embedded sensors identifying presence of people are linked to actuators

that respond and/or initiate behaviours such as *stay with me* by turning on or *follow me* by moving ahead a person walking or running.

When defining patterns and sequences of interactions, the challenge is to identify human-nonhuman communication.

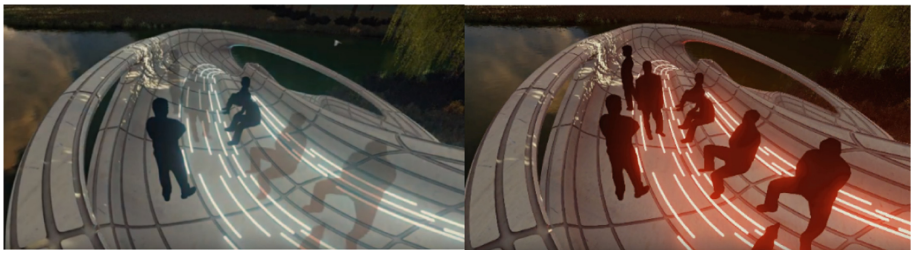

Fig. 5. Perspective view of the ambient in which dynamic lighting changes are taking place in relation to people's behaviours.

Relational Architecture. Relational architecture, as one of the DDs for Ambient UX, is intended as anticipation and/or triggering of most probable interactions to happen among actors involved in a particular system/situation/context (Fig. 6); it refers to understanding and mapping actors within a system and understanding and mapping stakeholders (it is to note that actors and stake-holders may occasionally overlap).

Students analyse and map out the social activities and relations happening within an existing environment. Furthermore, within the novel design concept they propose probable interactions and encounters to happen; meaning that in this manner the social relations are part of the design planning process and they are directional with certain enablers and/or constraints within the project.

Variable of Time. Variable of time, as one of the DDs for Ambient UX, is the backbone that puts together all the three architectures described previously; it refers to sequential steps of an activity, and it can reflect diverse time scales and length. When it comes to designing for experiences, story-mapping comes into play [6, 16].

Students analyse and map out time frames of their planed user journeys and activities within the interactive installation (Fig. 4, 5, 6 and 7). Time can be observed as an element that can be enabled or constrained by defining, for e.g., a period in which certain dynamic changes and interactions can happen.

By taking on the approach of designing for experiences, students focus on defining particular journeys, which happen over a certain timespan, i.e. they anticipate possible paths and moments of interaction and encounters, as well as their sequence. Design concepts considering time as a variable is communicated through design tools such as storyboarding, journey mapping, movie plots, etc.

Spatial qualities and functional requirements need to meet story-mapping, hence students identify spatial architecture requirements in relationship to physical and interactive experiences in time. In this context, the overlap and/or intersection between DDs

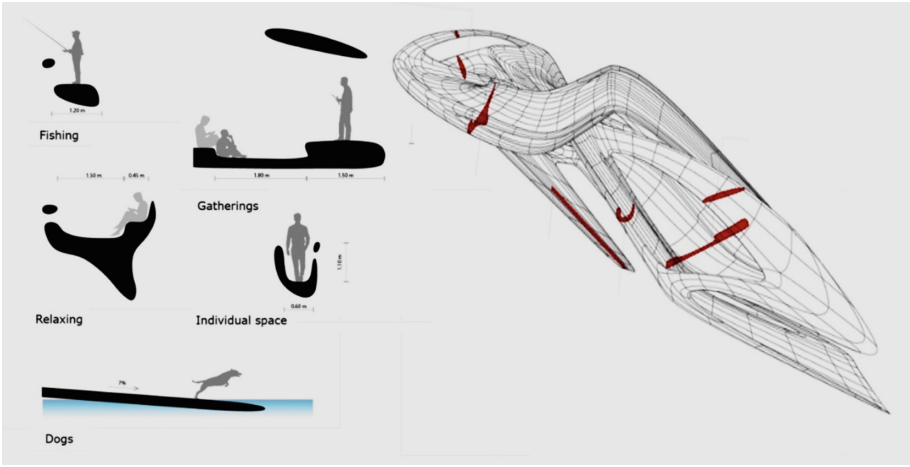

Fig. 6. Planning for probable social activities in relation to spatial qualities and functional requirements.

becomes evident and the interlaced D2RP&O approach becomes a requirement in order to address performances from the very beginning of the process.

When designing for experiences, it is to consider the traversing of the different DDs by identifying DD-specific tools and approaches that are used for modelling, simulating, and prototyping the three architectures. All are contributing to achieving continuous and cohesive Ambient UX across devices, time, and space.

3 Conclusion

This paper presented and discussed Ambient UX design approaches implemented in D2RP&O processes by analysing various case studies implemented at the Robotic Building Lab, TU Delft. All case studies involved the design of physical environments that are incorporating sensor-actuators, hence the DDs for Ambient UX were identified as concerning (1) physical environment and/or artefact (2) information flows and processing, as well as (3) social relations. DDs were discussed with respect to mapping activities through constraints and enablers and designing with time as a variable. The challenges to integrate the design of interactions with the design of physical environments were addressed by establishing feedback loops between D2RP and D2RO. The integration of the two relies on the understanding that the physical environment consists of building components that are cyber-physical in nature (Fig. 7) and their design is informed by structural, functional, environmental, and operational considerations [14, 17].

Architecture as cyber-physical system (CPS) is understood as a network of interacting elements with cyber/physical input and output. Presented studies showcased embedded wireless sensor-actuators that facilitate interaction with users through dynamic change of light patterns (Figs. 4, 5, 6 and 7). By embedding all cyber-physical requirements from the onset of the design process and by traversing the different DDs a continuous and cohesive Ambient UX across devices, time, and space is achieved.

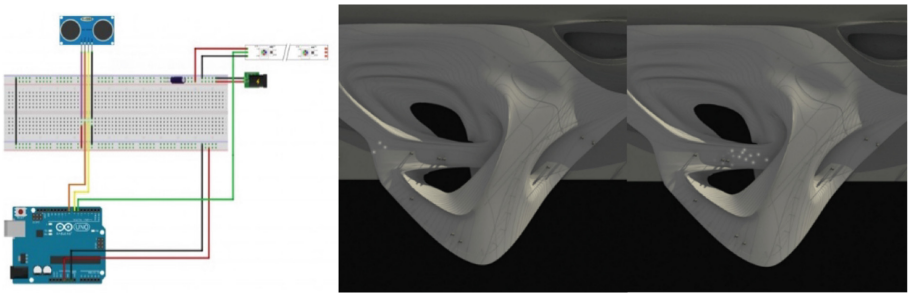

Fig. 7. Wireless sensor-actuators embedded into the built environment render the space cyber-physical and facilitate interaction with users through dynamic change of light patterns.

DDs (spatial, informational, relational) and time as a variable all sink into a holistic design concept when it comes to designing CPSs. The DDs derive from the already established fields, and thus, they are recognizable within design practices; they have different traditions regarding design methods and history of development, as some of them, like spatial architecture, are known and practiced for much longer time period than informational architecture, for example. The element that connects all DDs is the variable of time, which provides a backbone for planning and designing for human activities and interactions. DDs intertwine around the element of time and allow for planning and designing of touchpoints on various levels. Furthermore, as the DDs are known in design practices in terms of the final outcome of the concept and project development, design tools used in the practices are also quite known. The already known tools, being proven as efficient for their peculiar practice, can be used as a starting point for reasoning on a toolkit or a unique tool platform for designing cyber-physical systems.

The next steps in the development of Ambient UX within D2RP&O involves Artificial Intelligence (AI). Even though AI has been developed for several decades now [18], only in recent years it has started to emerge as a significant technology having a large impact in diverse application fields, where the question is not anymore if it will be implemented across industries including architecture and building construction but rather how it should be adopted efficiently [19, 20]. Future research would, thus, target novel design materials, processes and tools in order to establish a blueprint for designers and practitioners in the field. Emerging design approaches need to be discussed as levels of trust, intelligence, automated assistance, and others. The goal will be to provide tangible solutions for how to design interactions that foster trust, when and why to employ non-human-like embodiments of intelligence, how and why might AI resonate empathic responses, and similar.

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