CYBER-PHYSICAL DEVICES IN URBAN DESIGN: Towards the improvement of liveability in public space

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ABSTRACT

Cyber-physical devices are the backbone of a postdigital society in which social, virtual and real spaces are seamlessly integrated by ubiquitous computing and networking. Holistic approaches to urban dynamics cannot minimize the interplay between these spaces and the processes of such entanglement by interfacing augmented urban devices, and the societal pressing challenges of sustainability. The literature review and the production of an original case studies Atlas allowed to: (i) identify major trends on devices' design and deployment strategies, which, alongside a workshop, fed the design guidelines of a multidisciplinary R&D Project´s use case demonstrator; (ii) suggest the rising of new (or enhanced) types of urban devices that are the expression of sustainability concerns; and (iii) ascertain three main framing concepts (digital twin, interface and awareness) in light of what seems to be a necessary process of reviewing established urban design theories given a novel highly digitally mediated (virtual) reality.

Keywords: augmented public space; urban cyber-physical devices; urban design; sustainability**.**

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Thematic clusters: 1. City and project
Topic: Urban design and public space

1. Introduction

The Cyber-physical devices are the backbone of a postdigital society in which social, virtual and real spaces are seamlessly integrated by ubiquitous computing and networking. The increasing densification of such networks and our growing dependency on cyber-physical systems is a major factor for the need of an updated review on the complex relations between users, urban spaces and built environment. Alongside societal pressing challenges like sustainability, digitalization, 4th industrial revolution, globalization, and circular economy (intensified by current global crises), these aspects frame some of the most urgent issues of a growing urbanized society. Despite the potential (and dangers) of this ever-growing global technological mesh, much can be done locally. Responding to such challenges, a strategic Research Project gathers a multidisciplinary team from architecture, product design, polymer science and information and communication technology (ICT) R&D units, in the creation of pinpoint solutions of augmented interactive devices to support urban life (Fig. 1).

Urban Cyber-Physical Devices (UCPDs) are responsive urban devices comprised of deeply intertwined physical and software components (Khaitan & McCalley, 2015), and can be seen as a class of what has been called Cyber-Physical-Social Systems (CPSSs): The extension of Cyber-Physical Systems to seamlessly integrate cyber space, physical space and social space (Pasandideh et al., 2022), in the context of the (smart) city.

This synchronic coexistence has been changing how we use public spaces and the spaces themselves, as well as motivate the emergence of new breeds of augmented urban objects. These tools are the technologic pillar for Smart City sustainable urban transformation as they allow governance agencies to make informed decisions on urban matters. The combination and coordination between physical public space, urban (big) data and ICTs is tied to the concept of Smart City. Data collected by IoT enabled devices can be used to feed city *digital twins* with information from its state and environment. This is an approach to urbanization that uses innovative technologies to enhance community services and economic opportunities, improve city infrastructure, reduce costs and resources consumption, and increase civic engagement (Halegoua, 2020). At a smaller scale UCPDs are also main features of bottom-up *digital placemaking* interventions that, targeting local communities, contest technologic superstructures in the spirit of open-source culture, in a process that Sassen (2015) calls *urbanizing technology*.

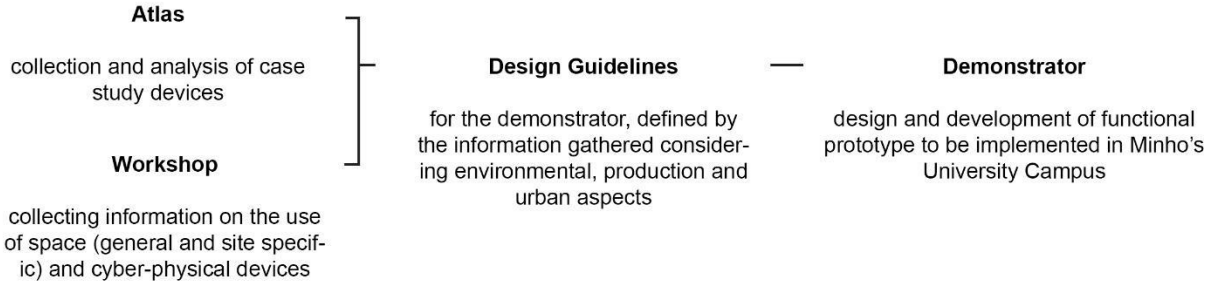


Fig. 1 Flowchart of developed works within the scope of the R&D project.

1.1. Hypothesis

Long before the digital revolution and the internet, the city and its public spaces design had become a question of process rather than product. The morphologic and physical dimension of urban settings is only a part of the urban design multidimensional approach to the city, involving perceptual, social, visual/aesthetics, functional, temporal and process control aspects (Carmona et al., 2011). Although fundamental, public space form and

urban objects interplay with activity and meaning to create *places* (Montgomery, 1998). The first manifestations of the crisis of *place*, with the consolidation of globalization and the emergence of the *network society* (Castells,

1996), mostly affect the meaning dimension of place disrupting stablished social and economic organization: a space of flows, tangibly expressed by what Augé (1992) as coined *Non-places*. However, the extents to which digitalization and virtualization impregnate the social infrastructures was mostly unforeseen in the outbreak of internet. With the massification of wireless internet and mobile devices, these have become both evasive and pervasive in current urban contexts.

The understanding of the processes of such entanglement can be valuably assisted by augmented urban objects themselves. Designed both to assist urban life and to improve our comprehension of it, they may feed data-driven and evidence-based design, management and decision-making processes. These devices influence in increasing people's awareness of sustainability issues and societal problems is related to its virtual and physical presence in the organization of public space, theme that we intend to study by analysing and exploring their formal design.

1.2. Research questions

The goal of this paper is to cast light on some of the problematics arising from four interrelated base research questions:

i. How is digitalization and virtualization affecting the social role of public space?
ii. How is our dependency on cyber-physical systems changing the way public space is being used and designed?
iii. How are the relations between public space, ICTs, cyber-physical systems and sustainability goals being expressed in public space and questioned by urban design?
iv. How are ICT and energetic and material sustainability technologies being incorporated into urban objects?

In the following sections we show the background investigation work of the Research Project to contextualize its final technologic and design objectives. This was made by the production of an Atlas of case study projects (*Atlas for the design of future e-cities*, https://tinyurl.com/mrm5mnws) and a design workshop which was introduced by a simple survey on participants use and knowledge on public space and mobile ICT technology. Firstly, we present the methodologic aspects of these endeavours, followed by main observed results and theoretical synthesis. The final discussion and conclusion section summarizes the findings, reopens the discussion (pointing to related themes that may gain relevance in the future), and describes the base Research Project demonstrator's design guidelines.

2. Methodology

The literature and case studies review were materialized in an Atlas that collects, labels, relates and organizes a corpus of heterogeneous cyber-physical projects deployed in public spaces around the world, and meant to be used as an easy to consult state of the art document. A workshop was also organized with the aim of creating a hands-on experience for its participants. Initial reflection was prompted by an individual survey on public and virtual spaces individual experiences, while teamwork and discussion were encouraged and framed by a set of theoretical and practical presentations on the design, deployment and functioning of interactive urban devices.

2.1. The Atlas

The Atlas is a compilation of UCPDs' case studies, presented as a set of records with a unified description and representation, allowing empirical cross-readings and quantitative analysis. Records were critically reviewed on: (i) the relations between public space, ICT, community and sustainability goals (physical, technological and social contexts); (ii) the embedding of interactive digital devices in public space (object and functioning); and (iii) the virtual extension of the devices (sensing, connectivity, urban data mining). It was methodologically devised after the definition of Atlas in Geography: a set of standardized thematic representations providing a comprehensive image of a territory: the Interactive Urban Cyber-Physical Devices subject. Because of the continuous emergence of new projects and technologies, the Atlas is designed with an open-ended chronological coded structure, receptive to new additions.

2.1.1. Case studies

Code	Name	Year	Location	Development Team
P08.01	DIGITAL WATER PAVILION [1]	2008	Zaragoza, Spain	Carlo Ratti Associati and MIT
P09.01	COPENHAGEN WHEEL [2]	2009	Copenhagen, Denmark	MIT Senseable City Lab
P11.01	21 SWINGS [3]	2011	Montreal, Canada	Daily Tous les Jours
P12.01	SMART CITIZEN KIT 2.1 [4]	2012	Barcelona, Spain	Fab Lab Barcelona
P12.02	AIRFIELD [5]	2012	Atlanta, Georgia	Ueberall
P12.03	BIRLOKI [6]	2012	Bilbao, Spain	Nerei Emotional Intelligent SL
P13.01	ARRAY OF THINGS [7]	2013	Chicago, USA	Urban Center for Computation and Data
P13.02	RESPONSIVE PUBLIC SPACE [8]	2013	Graz, Austria	ORTLOS Space Engineering
P13.03	PUZZLE FAÇADE [9]	2013	Linz, Austria	Javier Lloret
P13.04	BEACONS [10]	2013	USA	Estimate (Apple)
P14.01	TETRABIN [11]	2014	Chicago, USA	Sencity
P14.02	ACTIWAIT [12]	2014	Hildesheim, Germany	Urban Invention
P15.01	UNDERWORLDS [13]	2015	Cambridge, USA	MIT Senseable City Lab
P15.02	THE HEART OF THE CITY [14]	2015	Sidney, Australia	Anaisa Franco Studio
P15.03	MURMUR WALL [15]	2015	San Francisco, USA	Future Cities Lab
P15.04	RESPONSIVE STREET FURNITURE [16]	2015	London, UK	Ross Atkin Associates
P15.05	FUTURE FOOD DISTRICT [17]	2015	Milan, Italy	Carlo Ratti Associati
P16.01	PROJECT BUS STOP [18]	2016	Singapore	DP Architects
P16.02	TREE.0 [19]	2016	Copenhagen, Denmark	Interactive Spaces Urban Studio
P17.01	BENCHMARK [20]	2017	Cambridge, USA	Civic Data Design Lab
P18.01	INTERACTIVE SCREEN [21]	2018	Barcelona, Spain	Trison
P18.02	ITECH DEMONSTRATOR [22]	2018	Stuttgart, Germany	University of Stuttgart (ICD, ITKE, ITFT)
P19.01	SMART POLE [23]	2019	Holesov, Czech Republic	INELS (ELKO EP)
P20.01	AUGMENTED SPACES [24]	2020	Wellington, New Zealand	Holly Chan, Victoria University of Wellington

Table 1 List of recorded projects in the Atlas (please refer to links in the end of this paper)

The rationale behind the selection of examples followed a series of principles backing the main goal of portraying the diversity of contexts and scales, and the several design and deployment strategies of innovative UCPDs. Priority was given to objects with a physical existence (implemented or prototyped) that support typical human needs (mobility, comfort, security, etc.), over untested concepts, purely artistic interventions or digital-only initiatives. We have searched for examples that possess some sort of sensing, communication, interactivity or adaptability capacity that augments their physical performance and extends its existence into the virtual realm. The Atlas currently comprises twenty-four case studies (Table 1).

2.1.2. The records structure

Each project is bound to a four-page organization with two main foci: Object and Context (Fig. 2). The complete set of the records reading grid headings is: (i) Preview; (ii) Datasheet; (iii) Object; (iv) Context; and (v) Review.

1. (i) **Preview**. A bird's eye view of the project that summarizes its context and design concepts using highlighted tags, easy to identify and situate. This information is divided into five topics as shown in Table 2.

2. (ii) **Datasheet**. Situates the example with general information: project's official name, code, development team, third-party participation, development nature (e.g., academic, independent), location, year, keywords, related projects and references. An Overview topic describes the project by the development team's own words.
3. (iii) **Object**. Under this heading, the main design features and functions of the objects are organized. Stress is in the relations between the physical and digital components of the device, and the functioning of its associated interface. Topics are: *Design Principles*; *Shape and Material*; *Sensors and Connectivity Infrastructure Technologies*; and *Specific Functioning*.
4. (iv) **Context**. Addresses the presence of cyber physical technologies and interactive devices in the public space. The focus is on the urban contexts in which they are deployed and their influence in the design and functioning of the spaces, and in the people who inhabit them. Topics are: *Context Diagram*; *Context*; and *Induced Transformation*.

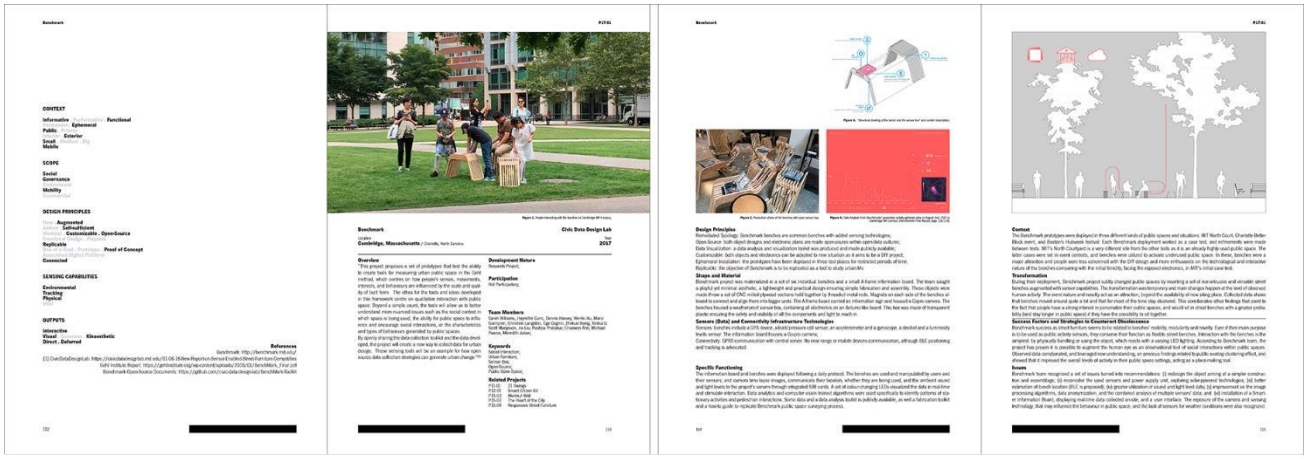


Fig. 2 The four-page record's organization in Atlas' BENCHMARK case study (P17.01). Reading grid, from left to right: Preview (page 1); Datasheet (page 2); Object (page 3); Context (page 4, top) and Review (page 4, bottom). Images in pages 2 and 3 from [20].

Table 2 Preview topics, subtopics, tags, and their description

Topic	Subtopics	Tag	Description
Context	Role	*Informative*	Media content and knowledge to inform or educate the users
		Performative	Ludic nature, with motion, interaction and animation
		Functional	Tied to an operative use, as a utilitarian device
	Duration	*Permanent*	Permanently installed or intended to be a permanent addition to the public space
		Ephemeral	Limited time span or seasonal implementation
	Ownership and Use	*Public*	Relates to devices of public use and domain
		Private	Can be bought and owned by the common citizen
	Site	*Interior*	Indoor setting
		Exterior	Outdoor setting
	Scale (comparative to human)	*Small*	Up to an outdoor bench
		Medium	Up to an urban kiosk
		Big	Bigger than an urban kiosk
		Mobile	Designed to be moved easily
Scope		*Social*	Tackles Societal issues (e.g. inclusive designs, community gathering and cooperation)
		Governance	Data driven decision-making and management (e.g. institutions, smaller business)
		Environment	Sustainable habits incentives, ecologic concerns and environmental comfort
		Mobility	Mobility in the cities, both transportation and walkability
		Commercial	Indirect impact in the city's economical fabric
Design Principles	Typology	*New*	New concepts or object types added to the public space
		Augmented	New digital functionality added to already stablished types of urban objects
	Support	*Add-on*	Attaches to a host object for structural and/or infrastructural support
		Self-Sufficient	Independent power supply
	Tailoring	*Modular*	Composed of modular parts
		Customizable	Made to be customized in its physical or digital components
		Open-Source	DIY, open-source and open-data initiatives
	Attachment	*Emotional Design*	Empathy, engagement and appropriation through shape, software and interface design
		Playable	Gamification of the urban spaces or activities
		Replicable	Possible to be reproduced and applied to a different context with no major adaptations
	Oneness	*One of a Kind*	Designed to be unique, usually artistic expressions
		Prototype	Device in the first development phases, with intention of mass production
		Proof of Concept	Device showcasing a new technology or concept, with no direct intention of further development
		Associated App	Devices that have an associated app or e-service, interfacing with a website
		Connected	Connected to any kind of public or private communication network (intranet, extranet or internet)
Sensing Capabilities		*Environmental*	Temperature, humidity, chemical/gas, ambient light and sound sensors
		Tracking	Optical, position/proximity, movement/displacement or network-based tracking
		Physical	Force/load, vibration, torque…
		Vital	Heart rate, blood pressure…
Outputs		*Interactive*	Devices that have interactive user interfaces
	Sense	*Visual*	Lightscapes, screens or other data visualizations, also through associated apps
		Sonorous	Soundscapes
		Kinaesthetic	Induce user's movement or have moving parts that change the perception of space
	Immediacy	*Direct*	Immediate response to user's inputs and showcase of real-time data
		Deferred	Outputs takes effect in the future, e.g. data for governance or behavioural change

(v) **Review**. A critique assessment of potential benefits and weaknesses of the project, both as an isolated and a contextualized object. Topics are as follows: *Success Factors and Strategies to Counteract Obsolescence*; and *Issues*.

2.2. The workshop

The workshop's main goal was to invite participants to design and develop interactive devices to be installed in a Campus' public square. Project and research experiences were guided by a multidisciplinary team that stimulated the reflection on the design and performance of devices and digital interfaces, and in their potentials to transform public space and community interaction. The workshop counted with twelve participants, students with an average age of twenty-two and balanced distribution of gender and courses (Product Design and Architecture), and presentations from invited professors from both schools.

Before the brainstorming phase, an introduction to the theme and a visit to the study site were made, as well as an online survey to the participants. Although touching various subjects, the latter was intended as brief and simple as possible, with multiple-choice and rating scale questions as a way for the participants start thinking on the workshop subjects and to collect basic information: (i) *On the participants*, (ii) *On participants' public*

space usage and mobility, (iii) *On participants' knowledge and opinion on the project site*, (iv) *On participants' use of ICTs and mobile devices*, and (v) *On participants' knowledge, experience with and opinion on UCPDs*.

After the first designs, there was a presentation on design for recycled plastic additive manufacturing with important notions on the elected fabrication process and its implications in the design's functionality and form. The workshop ends with the presentation of three interactive devices with sustainable environmental awareness and digital fabrication principles rooted in their design.

3. Results

3.1. From the Atlas

The selected projects reflect the extent of the research but also some of its limitations. Projects span over the last thirteen years and are mainly developed by academic teams. There is a Eurocentric unintentional bias (North America and Europe have the highest number of projects). In this chapter we theorize according to analytic and empirical observations on the existence of UCPDs and their relationship with the built environment.

3.1.1. Mapping the relations between case studies

Keywords were empirically assigned to projects and ranked based on their specificity and significance, from generic (lower rank) to particular (top rank). In Fig. 3 related projects are connected by edges via keyword sharing, which are weighted by inverse ranking order. The strength of the relation is determined by the weights sum. The disks size at right represents the number of times a project is referred to.

From the results of this analysis, we can observe that:

1. (i) The stronger link is SMART POLE - BIRLOKI, followed by 21 SWINGS - ACTIWAIT, and MURMUR WALL - THE HEART OF THE CITY. This depicts some groupings: UCPDs as smart city equipment; UCPDs as social and activity stimulators; and UCPDs as public art media;
2. (ii) The most referred project is 21 SWINGS, then RESPONSIVE PUBLIC SPACE and TREE.0, followed by BENCHMARK, highlighting the importance of examples related to social interaction, and design principles based on playable strategies and kinaesthetic interactions;
3. (iii) The project BEACON is never pointed out as a related project. As a technology it was deemed too generic, so relations to other projects are weak;

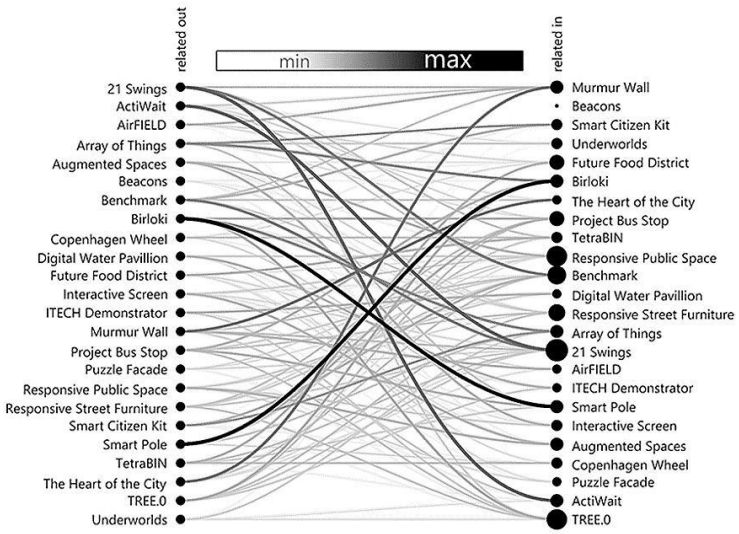


Fig. 3 Diagram of the relations between Atlas records, via keywords

4. (iv) The most used keywords are: Urban Furniture, Public Open Space, Human Tracking and Social Interaction. This may reflect a bias in the designer's viewpoint and examples' selection;
5. (v) The keywords more often ranked on top, producing the strongest simple links are Smart City, Sensor Box, Big Screen and Art Installation. This corroborates the results described in (i) and the importance of screens, yet the standard user interface.

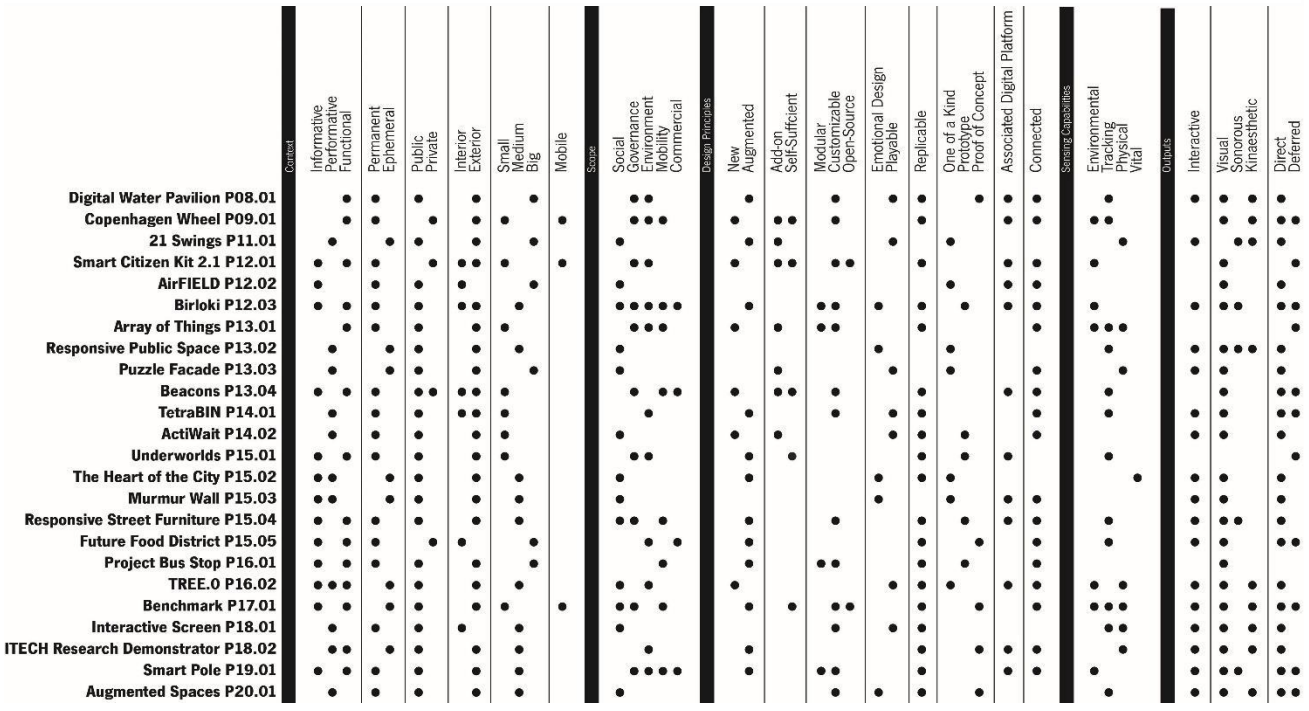
3.1.2. Empirical results from cross readings

In this section we summarize the Atlas' records cross readings, following primarily the topics of the records reading grid headings Context and Review outlined above. We intend to give a clearer picture of the main problems, common solutions and affinities between projects. In Table 3 a *case study project names – preview tags* matrix summarizes the tags highlighted in the Preview first page of each record (tags description, and topic/subtopic grouping can be acquired from Table 2).

(i) **Context**

- Most devices are deployed in developed countries (see Table 1);
- Issues addressed: environmental sustainability, public participation, community resilience and security in public spaces;
- There are usually installed in open public spaces seeking for high activity or pedestrian flow, such as squares, boulevards or important street intersections;
- Some cases are connected to indoor activities and entertainment, and others are mobile, therefore not site specific;
- Most devices are designed to interact directly with pedestrians instead of cars or traffic, notably a fruitful trend targets disabled people and assisted living in public space;
- Some devices are installed in segregated spaces, aiming at their activation;
- Cyber contexts (network scale) also vary from direct physical interfacing, or in-place mobile device pairing, to global internet connectivity;

Table 3 Case study project names – preview tags matrix



• The deployment time frame of research or artistic based interventions is short, while functional and industrialized products are designed to endure harsh outdoor conditions for long periods;

(ii) **Induced transformation**

- Physical presence is the only tangible direct transformation in the public space perception;
- Data collection is the base of governance informed decision-making (that leads to other tangible and intangible transformations);
- Behavioural change, namely sustainability awareness, is an indirect transformation;
- Social inclusion, encouraging rupture of bias and prejudice;
- Urban setting activation (foments social interaction and permanence);
- Facilitation of quotidian tasks;
- Enhancement of city infrastructures that can improve safety and impaired inclusion;

(iii) **Success factors and strategies to counteract obsolescence**

- Successful interventions oftentimes rely on opportune timings and placement;
- Suitable selection of deployment sites (where interaction is welcome by the users) are important aspects to consider;
- Direct object design parameters, such as safety, weatherproof, durability, anti-vandalism or modularity and adaptability to context;
- Devices' designed physical affordances can be a safe fall-back in case of digital failure, and a way to avoid object's obsolescence as a whole;
- Providing enjoyable experiences as well as a sense of discovery through emotional design.
- Perceived utility of the device;
- Inclusive goals (ethnographic, age groups and disabilities) through its formal design and intuitive user-friendly interface;

(iv) **Issues**

- Although there are low-cost technology and DIY solutions, large scale implementations are yet too costly to produce and maintain;
- Obsolescence due to excessive reliance on high-end technology, high maintenance, third-party services, mandatory smartphone apps or even continuous service content feed;
- Heavy dependence on novelty, perceived usefulness and user attachment may lead to trivialization;
- The inequality of access to ICTs, digital illiteracy or the bodily condition of users to operate physical interfaces;
- User safety concerns (ergonomic and placement as well as personal and site data security assurance);
- Although sustainability is an ever-present leitmotif, ecological impact of the UCPDs we have studied is not a main consideration concerning recycled materials usage, sustainable fabrication processes or renewable energy sources.

3.2. From the workshop

The results on the workshop kick-off survey (Table 4) focus on its (ii), (iv) and (v) sections that are of general relevance to the paper subject. The participant teams' final design proposals (Fig. 4) were: (i) *Interactive Chaise*, a modular system of augmented furniture parts that personalize and improve existing seating with shade and comfort; (ii) *AsSentar o Lixo*, a simple but versatile set of pads stored on-site improving comfort and usability; and (iii) Water Collector, a rainwater storage solution aiming at increasing awarness of the sustainability problematic of water as a scarse resource.

The survey had twelve completed responses. The sample is exceedingly small and biased (low diversity, close context and structure of questions), hence there is no intention to generalize results. Even so, main results may be empirically read as follows:

• Meal spaces seem more important than internet and media in public spaces;

Fig. 4 Workshop design proposal. From left to right: (i) Interactive Chaise, (ii) AsSentar o Lixo, (iii) Water Collector

- Everyone owns and uses the smartphone extensively, most consider it sufficient. Work conditions seem to be adapting to it (in the library smartphone is more used than laptop);
- Conditions are unfavourable for the (desired) use of laptop in public spaces;
- Play and playability are not important in the use of mobile devices but major as an UCPD design strategy;
- To play, watch video streaming and news, are all low rated. These can be considered personal habits and not transversal activities, subject to strong sampling biases (this is a generic issue);
- Listen to music is a major use of mobile devices, both smartphone and laptop;
- Although participants claim to be familiar with the concept of UCPD, but the perceptions are diverse, and the examples given are generally poor and mostly functional;
- Entertainment is low rated when asked for main uses of UCPDs (although most of reviewed case study UCPDs have a ludic nature);
- Sustainability and environmental issues are main concerns;
- Security is exceptionally low rated. There is a sense of security in the Campus and the community in general;
- The existence of places to teamwork is deemed not important. Online platforms have been assimilated;
- Participants seem to project the use they make of the smartphone into what they think is the usefulness of UCPDs.

Table 4 Main results from the workshop kick-off survey

(ii) On participants' public space usage and mobility	how do you usually go to school?	by car/motorcycle 41.7%; by foot 33.3%; public transport 25%;
	how long does that journey take?	min - 5 min.; max - 67 min.; average - 26 min.;
		more than half (7) take less than 15 minutes, from there, only 3 use car/motorcycle;
	most frequent activities in public spaces	(i) direct routes (home to school, home to supermarket, etc.) and walk, relax;
		(ii) hanging out with friends;
		(iii) walk the pets;
		no elections in: read and activities with children;
	most used public spaces	(i) street; square;
		(ii) urban park; esplanade;
		(iii) local gardens; coffee shop;
		(iv) library;
	what characteristics do you appreciate in public spaces?	(i) have natural elements;
		(ii) safe place; beautiful place; well equipped (benches, drinking fountain, etc.);
		no elections in: lively place; constant change; being able to remain anonymous; internet connection; have tv and music;
(iv) On participants' use of CITs and mobile devices	do you have a smartphone?	all participants do;
	do you use Wi-Fi or mobile data on your phone?	most use both equally;
		only two participants use mobile data exclusively;
	usually, where do you use mobile devices?	smartphone is used everywhere;
		laptop and smartphone are the most used (equally) at home and school/work;
		smartphone is more used than laptop in library;
		outdoors, the most used is the smartphone, then smartwatch;
		laptop is very used in coffee shops and esplanades;
	apart from calls, what do you use your smartphone for?	(i) listen to music;
		(ii) information search, contactless payments;
		(iii) social networks;
		(iv) google maps/orientation;
		(v) work;
	would you use your laptop for the previously indicated activities?	most would like to use the laptop in public spaces; a third considers the smartphone sufficient;
	if you answered positively, what would you use the laptop for?	(i) information search;
		(ii) read, study or work;
		(iii) listen to music;
		(iv) news;
		(v) social networks;
		(vi) streaming services;
	in your opinion, what is lacking in the public space for a more frequent use of the laptop?	environmental condition protection (from rain); energy plugs;
		faster and free internet connection;
		places to put the laptop and use it comfortably;
(v) On participants' knowledge, experience with and opinion on UCPDs	did you already know the concept of UCPDs?	all participants knew the concept;
	can you name any that you've interacted recently?	car parking free space indicators; interactive kiosks; device charging station; ticket machine; water dispenser; interactive maps; automated lighting; access control cards and chips; contactless payment; automated tools;
	in your opinion, what are the areas where the implementation of UCPDs have the most potential	(i) vacant spaces activation;
		(ii) sustainable urban mobility (bike, e-scooter, walk, etc.);
		(iii) potentiate local economy; potentiate tourism; increase environmental awareness;
		(iv) public space safety;
		(v) entertainment;
	in the Campus square, what are the areas where the implementation of UCPDs have the most potential	(i) energetic and waste management and sustainability;
		(ii) media and information communication; social interaction (make it a more pleasant space to gather);
		(iii) increase environmental awareness;
		(iv) social interaction (make it a more pleasant space to gather);
		no elections in: public space and urban infrastructure management; public health and active life; potentiate local economy; potentiate tourism;

3.3. Three cyber-physical meta concepts: digital twin, interface, awareness

From a literature review on the design perspective on UCPDs, and the process of elaboration of the Atlas itself, a set of framing meta concepts were synthetized regarding UCPDs and their incidence in the public space. Without the objective of reaching closed concepts, we have identified the following: *digital twin*, *interface* and *awareness*.

From the engineering and CAD industries, *digital twin* is the real-time digital representation of a physical object or process, integrating sensor data that can be used to manage the real world (Fuller et al., 2020). The responsive nature of UCPDs and their double physical and digital presence in the public space rekindles its use, counteracting a sense of alienation from place and architecture. Regardless of its complexity, the convergence between virtual and real worlds seems undeniable and it depends on the interface's conspicuity.

Interface is a fundamental concept in architecture and urban design, traditionally understood as the symbolic boundary between public and private realms or the physical surface that separates different spaces. With the introduction of cyber technologies, it could also mean the active control over building elements and adaptable spaces. Interface design is paramount in the engagement of people and UCPDs' success, becoming a synonym of functioning (Dade-Robertson, 2013). In the technological mediated realm of contemporary societies, UCPDs are regarded as the interface layer between a set of increasingly overlapping spaces and interconnected networks (Fig. 5). Interface is the place where communication and interaction happens, therefore it is the place where awareness rises.

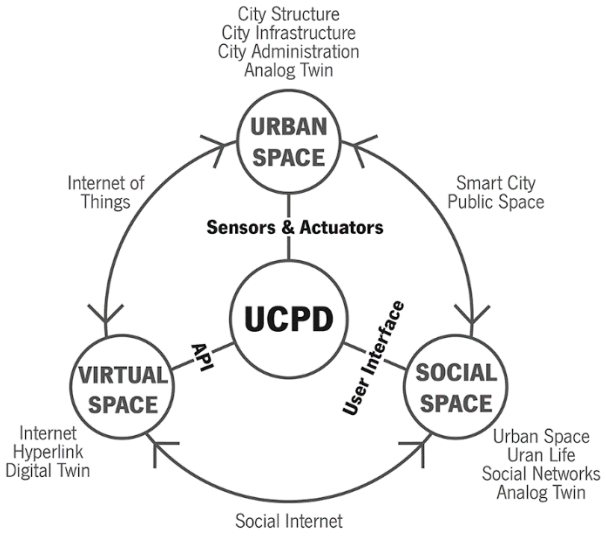


Fig. 5 Conceptual diagram with UCPDs as the central interface node of a network of networks and as a gateway between social, virtual, and urban spaces

The concept of *awareness* seems to frame the main goal for the implementation of cyber-physical devices in the city and the notion of Smart City itself. Awareness is synonymous of knowledge and perception, but also consciousness, sensitivity, and familiarity. This broad concept can be applied to people, machines, the relation between them, and between them and their environment. Public space users' increased awareness of global pressing issues is a key factor to participation and engagement and a main drive for the implementation of ICT technology. Awareness is the first step to behavioural change and social transformation which is the very base of a sustainable future. Developments in ICT technologies also look to increase not only the machine's awareness of its users but also of other machines and its environment in (increasingly autonomous) automated networks of devices that keep alive a digitalised world that seems to dispense user's intervention (Pitt, 2015). The increasing dependency on ICTs may be seen as both an opportunity and a threat, but awareness is ultimately understood as human knowledge, literacy and conscious use of machine, and participation in a virtual world built to deal with real problems.

3.4. The rising of new (and enhanced) types of urban devices

Although it is too soon to establish the emergence of new typologies, UCPDs gave rise to new classes of objects deployed in public space with a distinct image and functioning. We have identified and named three instances: (i) Sensor Boxes, (ii) Smart Trees, and (iii) Chargers. (i) Sensor Boxes are small UCPDs devoted to sense the city, with the sole function of collecting urban data, (mainly environmental). They range from institutional ICT infrastructures to simple DIY devices in the open-source spirit, merging ecological concerns with digitalization. (ii) Smart Trees are tree-like free-standing structures, devoted to collect sun power, with their photovoltaic "leaves", for charging battery devices, usually acting as Wi-Fi hotspots. Placed isolated in urban squares they are also shading structures and meeting points with interactive features. With the multiplication of battery devices and electric mobility, the need for autonomous or integrated (iii) Chargers in the public space has increased. From electric car pole chargers to personal devices' USB chargers integrated in solar urban furniture, these devices are becoming pervasive. We notice that these new classes of objects are mainly sustainability-oriented, and design/technologic solutions are varied. This seems to point to an evolutionary process of design experimentation (Marshall, 2009) in which the outcome is yet unforeseen.

4. Discussion and Conclusion

Contrary to the idea that virtual space deprives public space and collective life of its physical substrate, the Atlas reveals examples of innovative urban cyber-physical devices that show how the dynamics between real and virtual, between physical and digital spaces, are allowing their reviving. Contributing to a reinvention and diversification of uses and activities in public space, these devices counteract mono functionality and access restriction, and foster innovative strategies for inclusion, local economic opportunity and sustainability awareness, most of the time integrated in *digital placemaking* interventions.

The social role of public space is as important as ever, and the tone is in augmentation, hybridization and complementarity and not competition or predation. More than a crisis of public space, there is a sense of crisis or backwardness of the urban design practices and theories in incorporating this new (virtual) reality. Established urban design theories, frameworks and concepts concerning human needs satisfaction, human behaviour and activity, the social role or the quality assessment of public spaces may need review considering the digital revolution. For instance, (Seeburger et al., 2015) points that Gehl's (1987) categorization of fundamental activities (necessary, optional and resultant/social activities), and their interrelations as function of the physical quality of public urban places may be subverted by ICT devices. The use of location-aware and internet technology can create new optional activities resulting from digitally mediated social interaction between collocated people not depending on the physical characteristics of the space. The artefacts that allow interfacing between the physical and digital layers (screens, QR codes, beacons, etc.) are changing the appearance of public spaces. While it does not necessarily turn them more inviting or enjoyable, they provide new opportunities to optional activities, potentially turning them more meaningful for users. Also William Whyte's (1980) *Self-congestion* or *Triangulation* patterns of human behaviour in public space, or the appropriation by urban design theories of concepts like *copresence*, e.g. (Hillier & Hanson, 1984), must be review as these evolve to embrace new forms of highly mediated social interaction. The meta concepts we present, or redefine, in this paper (*digital twin, interface, awareness*) are exploratory framing concepts in the light of which these reviews may be pursued.

In this context, territorialisation of the virtual realm is pursued by design resorting to location and event-based ICT technologies, small scale networks and alternative means of interfacing. Giving physical expression to the intangible digital layer seems to be a most important aspect of the design of UCPDs for public space. Besides formal aspects of the device, strategies include turning the user's interaction public and socializing the use of mobile devices, counteracting the excessive dependency on those by stimulating collocation interaction and equilibrium between face-to-face and deferred and/or remote interaction.

At a global scale, both public space and ICTs, are key factors in reaching UN Sustainable Development Goals and targets (UN DESA, 2022). Public space is per se an important asset regarding sustainability, mostly in

developing countries (Kristie, 2016), and ICTs are both identified as targets and cross cutting tool to be utilized for the achievement of all the SDGs (Tjoa & Tjoa, 2016). At a local scale, digitalization and sustainability come together in new classes of urban objects and installations. As most of the technologic solutions are experimental, their roles are mostly of proof of concept and pedagogical. Sustainability is both a theme of physical and interface designs of UCPDs, besides digital and media content to be displayed and interacted with.

Nonetheless, while integration of ICTs and energetic sustainable solutions (mainly renewable solar energy) is well developed, notably in solar smart urban furniture and urban IoT devices, the integration of ICTs and material sustainability, related with circular economy, recycling and digital fabrication, is less developed and integrated. Our ongoing Research Project demonstrator design has the goal of contributing to close those gaps, by encompassing digital components incorporation, solar-power energy, and recycled plastic additive manufacturing into a site-specific meaningful whole.

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List of links to Atlas projects' case studies in the web:

[1] https://carloratti.com/project/digital-water-pavilion/

[2] https://www.senseable.mit.edu/copenhagenwheel/

[3] https://www.dailytouslesjours.com/en/work/musical-swings/

[4] https://www.smartcitizen.me/

[5] https://ueberall.us/portfolio/airfield/

[6] https://www.juansadaba.com/projectbirloki/

[7] http://www.arrayofthings.github.io/

[8] https://www.ortlos.com/projects/responsive-public-space/

[9] http://www.puzzlefacade.info/

[10] https://developer.apple.com/ibeacon/

[11] http://www.tetrabin.com/

[12] http://www.urban-invention.com/

[13] http://www.underworlds.mit.edu/

[14] https://www.anaisafranco.com/heartofthecity/

[15] http://www.future-cities-lab.net/murmurwall/

[16] http://www.rossatkin.com/wp/?portfolio=responsive-street-furniture/

[17] https://carloratti.com/project/future-food-district/

[18] https://www.dpa.com.sg/projects/projectbusstop/

[19] https://interactivespaces.dk/tree-0/

[20] http://benchmark.mit.edu/

[21] https://www.trisonworld.com/en/projects/trison-digitalise-shopping-center-arenas-barcelona/

[22] https://www.itke.uni-stuttgart.de/research/icd-itke-research-pavilions/itech-research-demonstrator-2018-19/

[23] https://www.elkoep.com/smart-pole-in/

[24] http://www.ecaade2021.ftn.uns.ac.rs/session-16/