Chapter 3

Designing and prototyping smarter urban spaces

3.1 Defining urban technology

In the inaugural issue of the *Journal of Urban Technology* (JUT) published in 1992, the editor Richard E. Hanley declined to define the term urban technology. Instead, Hanley offered a "functional description" of the journal's purpose as the examination of "… the interaction between cities and technologies for a general audience whose businesses, occupations, or studies demand that they know what technologies do to cities and what cities do to technologies" (p. v). Hanley added that the goal of the journal was to enable "…people to better understand both cities and technologies so that they can improve the former by wisely using the latter" (p. v). For the JUT, the definition of urban technology has remained open to interpretation and contingent on perspective and context. As technologies and urban environments have changed over the subsequent decades, the contributions to the JUT have shaped a discourse in which the concept of urban technology has also continually evolved.

The concept of urban technology has been commonly associated to large-scale infrastructural systems of the modern city such as roads, bridges, public transport, sewers, waste disposal facilities, and telecommunications (Tarr, Konvitz, & Rose, 1992). Yet, and in a demonstration of the term's elastic character, horses have also been described as an urban technology (Tarr & Mcshane, 2008). This is because, in the 19th century horses were a source of power that humans used to help achieve their goals. Tarr and Mcshane (2008) describe how 19th century business owners valued horses for their labour power and viewed them as "machines". Horses were a primary way to power agricultural and industrial machinery such as the horse-drawn Furrow plough. Horses were also used to power the transport of freight and passengers in and between towns and cities. As such, in the 19th century, horses were instrumental to the flow of people, information, and goods in cities and in turn, central to the functioning of the economy more generally. Yet, by the early 20th century actual horse-power had been largely superseded by fuel-powered automobiles and electric-powered machines, trains, and trams. Fast forward to the 21st century, and the

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concept of urban technology has taken on new meanings associated to the literal fusion of information technology with the urban environment and smart things, and technologies that build on this infrastructural foundation, including virtual, digital platforms, products, services, that also shape the flow of people, information, and goods at multiple scales.

Urban technology now also refers to an established field of tertiary education and a specialist technology sector. In the United States, Director of the Urban Technology Program at Taubman College at the University of Michigan, Bryan Boyer (2022), describes urban technology as, "… digitally-powered *products and services* that affect how cities are seen and made sense of, how they're shaped and built, and how urban spaces are inhabited" (my emphasis). In one sense, this definition of urban technology appears broad as it infers a potentially vast ecology of digital technologies. In another sense, however, it also reflects a market and consumer-oriented view of urban technology as the creation of information systems and platform-based services. This perspective is also echoed by the Urban Tech Hub of the Jacobs Technion-Cornell Institute at Cornell Tech in New York City, the United States, which describes its aim to "train the next generation of technologists" to identify and solve urban challenges.[a]

Patrick Adler and Richard Florida (2021) use the term "urban tech" to refer to commercial digital platforms such as "ride-sharing, home-sharing, smart cities, urban delivery and more", that also aim to address large-scale problems associated to urban agglomeration (p. 1). They report that since the mid 2010s there has been a rapid increase in enterprise-led, platform-based digital technology solutions that capitalize on existing information communications infrastructure and hardware owned and operated by individuals, namely smart phones. Analysis undertaken by Florida, Adler, and Hoelzer (2021) found that "global venture capital investment in urban tech surged from virtually nothing in 2010 to … $70 billion in 2018". With this, urban tech assumed the status of a specialist subfield of the technology industry, akin to the venture capital buttressed sectors of financial technology (FinTech), education technology (EdTech), and medical technology (MedTech).

The growth of the urban tech sector has also influenced shifts in *who* is leading and shaping the convergence of the urban and the technological, with significant implications for its (im)materiality, and issues of responsibility, accountability, and environmental impact. The urban tech sector markets its products to governments and municipalities to help them deliver smart city initiatives, but it is also a sector that extends beyond smart cities and delivers direct-to-consumer models of urban tech that include "ride-sharing, co-living, co-working, bikes and scooters, food delivery, real estate and property tech, and construction tech" (Florida, 2018). With this, government and municipal entities who have traditionally overseen how technologies are integrated with

a. https://urban.tech.cornell.edu.

the urban and are accountable to public citizens, are being side-stepped by enterprises and high-tech start-ups who are aggressively competing for venture capital-investment, and who, despite claims to advancing a triple bottom line, are chiefly answerable to shareholders.

Enterprise-led urban tech favors software-based solutions over hardware-based solutions and heavy physical systems. This makes sense given it is far easier to "move fast and break things" that are not bolted down or encased in concrete and steel. Yet, the infrastructure-lite propositions advanced by both the smart city and the urban tech sector are also misleading. Urban technology is almost always an entanglement of hardware, software, physical materials, and living phenomena. Even though urban tech services and products are marketed as software-based solutions, they rely on heavy physical systems and hardware that are located *somewhere*. Urban tech inherently engages with and negotiates between the physical-material and cyber-computational realms. And while the services and products that characterize the urban tech sector do not literally disembody citizens, the habituation of immaterial digital experiences that urban tech perpetuates can foster a kind of material forgetfulness. This matters, as L. M. Sacasas (2021) writes, as a forgetting of the material realm and of the body "… may also be prompting us to act as if we [are] self-sufficient beings with little reason to care for or expect to be cared for by another".

Accordingly, urban technology is examined here with an equal emphasis on the "urban" and from the perspective of context, situatedness, materiality, and embodiment. Urban technology is further understood here in ways that are analogous to the term building technology, that typically refers to the integration and interplay between technological systems and services and the physical, material, and spatial organization and performance of buildings. As such, the urban technology projects featured in this book are those that involve sensor-based technologies and physical computing and are thereby materially or tangibly implicated in both the physical and performative dimensions of the urban environment. Put another way, the materials of the (urban) design situation are taken here to include physical-material phenomena in conjunction with sensor-based technologies, such as movement, pressure, sound, light, and proximity sensors, and video cameras, Wi-Fi, and Bluetooth tracking, and physical computing and dynamic actuation (Coyne, 2010; Khan, 2018; Koolhaas, 2015; Mitchell, 1996, 2003; Shepard, 2011).

The following sections of this chapter outline how a spatially and materially attuned approach to the design of urban technology has shaped an undergraduate course in the computational design specialization at the University of New South Wales (UNSW) in Sydney, Australia. It outlines how the smart city, the IoT, and cyber-physical systems are explored from a sociotechnical perspective and through practices of design and prototyping. It sets out an integrated approach that combines methods and thinking from spatial, interaction, and computational design, which is operationalized through a cross-scale design framework that shifts through and between scales of design thinking. Finally, it frames speculative urban technology projects as thought experiments to materially surface and explore ethical issues. The chapter concludes by outlining the core themes that organize selected urban technology case examples and speculative urban technology projects that are included in subsequent chapters of the book.

3.2 Designing urban technology

Given the significance of sensor-based technologies and computational systems to the practical and economic functioning of contemporary cities, as well as citizens' experiences within them, the responsible design of urban technology has become a significant focus of existing and newly established education programs in tertiary institutions around the world. This includes the undergraduate Computational Design (CoDe) program specialization at the University of New South Wales (UNSW) in Sydney, Australia, which was established in 2015 to address a digital and computational literacy skills gap in the architecture, engineering, and construction (AEC) sector. The concept of digital literacy is significant here as it infers more than simply teaching students how to code. Rather, the notion of digital literacy speaks to the necessity to connect between the development of technical proficiency and knowledge and critical thinking and problem-solving skills.

The CoDe specialization aims to foster creative, critical, and responsible approaches to the design of digital technologies and computational systems in and for the design, production, and operation of the built and urban environment. It does so through a combination of technical methods-based courses as well as courses that focus on the various ways that "… the digital, spatial, and social fold into one another" (Coyne, 2010, p. xvi) to animate critical inquiry. Design technology is a catch-all term that refers to the study, creation, and use of digital technologies and computational design thinking and methods across various scales of design practice—from the design of an object or room to an urban region. Design technology methods can include, but are not limited to, parametric 3D modeling, generative design, simulation analysis, and data collection, analysis, and instrumentation techniques to aid design decision-making and optimization processes (Bernal, Okhoya, Marshall, Chen, & Haymaker, 2020; Bradner, Iorio, & Davis, 2014; Gardner, Haeusler, & Zavoleas, 2020). In the AEC sector, design technologists and computational designers typically create processes using software applications and programming languages to automate tasks, to access and instrument datasets, to execute analytic processes, and to instruct computer-numerically controlled (CNC) fabrication machines.

Design technology tools can create efficient, yet comprehensive ways to access and instrument a wide range of external data sources in and for the design process, such as climate data or open access government census datasets. This extends to the creation of data-driven 3D modelling simulations that can for example simulate and predict pedestrian activity, the urban heat island effect, and embodied carbon and waste generation to better understand the potential consequences of material and spatial design choices. Students, researchers, and professionals engaged in the design of the built and urban environment create and use design technology tools to identify and investigate a plurality of project parameters and perspectives and to model and predict the social, economic, and environmental consequences of design decisions at a range of scales.

Graduates of the CoDe program are designers who work in the AEC sector and are skilled in navigating, evaluating, creating, and communicating design technology and urban technology solutions effectively and responsibly. While design technology refers to the use and creation of digital tools, software solutions, and computational methods to aid the design process, urban technology refers to the integration of computing technologies and computational systems for but also *within* the urban environment. The focus of the CoDe course *Ubiquitous Cities*, which takes its name from the 1990s computer science concept of ubiquitous computing (ubicomp) that imagined a post-desktop future of distributed computing, is more specifically focused on the design of urban technology projects. While the *Ubiquitous Cities* course pays obvious homage to ubicomp, it also explores the use of sensor-based technologies for physical or tangible computing and embodied interaction in the urban environment, and to critically challenge ubicomp's, and by extension the smart city's, prevailing logic of pervasive, invisible, calm, and ambient computing.

3.3 Interdisciplinary and integrated urban technology design

The *Ubiquitous Cities* course adopts an interdisciplinary and integrated approach to the design of urban technology that combines spatial design thinking and computational thinking with user-centered design methods and interaction principles from the fields of human computer interaction (HCI) and interaction design (IxD). This matters because, as Bryan Boyer reflects, "[w]hile building urban technologies involves new hardware and software to be created, computer scientists alone cannot reimagine urban life any more than architects or urban planners can reimagine the digital" (Boyer, 2022). In this way, the course reflects a growing need for design practice to traverse across fields and sub-fields such as architecture, landscape architecture, and urban design to computer science, HCI design, and IxD.

Numerous scholars argue that the design fields of architecture and IxD are already "intertwined", share many overlaps, and are on a "convergent course" (Benyon, 2014; Bratton, 2008; Coyne, 2010; Dade-Robertson, 2013; Dalton, SchnäDelbach, Varoudis, & Wiberg, 2016; Hespanhol, Haeusler, Tomitsch, & Tscherteu, 2017; Mccullough, 2013; Wiberg, 2017). Yet, while these fields complement each other they are also distinct in several core ways. Most obviously, architects, urban designers and those working in the fields of HCI and IxD have traditionally designed at different scales. Mikael Wiberg argues that "interaction design has to a large extent been about the design of interactive objects—interactables … that are useful as tools, meaningful, easy to carry around and easy to use … Architecture operates at a different scale from objects" (Wiberg, 2017, pp. 64–65). Design sites for architects and urban designers are typically physical buildings and urban spaces that are *inhabited* and not simply used and relate to an extrapersonal scale or social space.

For HCI designers and interaction designers, design "sites" have traditionally been computer systems, software interfaces, digital devices and interactable objects that pertain to a peripersonal scale or user space. As such, while architecture and urban design design focuses on a social or spatial scale and pertains to the organization of forms, surfaces, and materials (the physical elements that collectively define space) to support a range of known and unknown activities, design in HCI and IxD is typically user-centered and task-oriented. This means that HCI designers and interaction designers are attentive to notions such as activity, experience, sequences, journeys, and decision-making pathways in relation to specific goals. As such, while spatial form, function and embodiment are central concepts in architecture (design for social bodies), foundational perspectives in HCI and IxD have centered on ergonomics, usability, and interaction (design for the body) (Kirsh, 2019; Wiberg, 2017).

HCI and IxD are relatively young fields that have evolved in parallel with advancements in electronic and digital computing since the 1970s. John M. Carroll (2001) writes that HCI was initially envisioned as an applied science that aimed "… to bring cognitive science methods and theories to bear on software development". However, the focus of HCI, as well as its unit of analysis, has also changed over time from system-centered in the 1970s, and user-centered in the 1980s, to situation or context-centered in the 1990s. Third wave HCI was particularly influenced by science and technology professor Lucy Suchman's (2007) pioneering work in the 1980s that demonstrated how socio-organizational contexts can influence human-technology interaction and the ability to realize system goals. Following third wave HCI, Carroll (2010) writes that IxD and user experience design came to be seen as distinct subfields of design that focused on interactive systems, objects, and experiences (p. 4).

Designing how humans interact with computers, and computing devices in HCI and its associated subfields however has traditionally been more procedural than interactional. Dourish (2004) notes that, "HCI, from its very beginning, took on the trappings of the traditional computational model and set out its account of the world in terms of plans, procedures, tasks, and goals" (p. 4), to meet goals of usefulness, usability, efficiency, and productivity (Wiltse & Stolterman, 2010). David Kirsh (2019) argues that the procedural perspective is deeply ingrained in HCI and its subfields and is a factor that distinguishes it from architectural design. Kirsh (2019) characterizes this difference as the design of "state space" in HCI and the design of "social space" in architecture (p. 6). He reasons that unlike the design of software-driven systems, "Architectural space is not usefully conceptualized as an environment of forced choices" (p. 6).

Social space or spatial co-presence, Kirsh argues cannot be reduced to an "… intellectual understanding of problem space, task structure, and sub-goal structure" (Kirsh, 2019, p. 39). In other words, the social space of the material-physical world is difficult to comprehend only through the lens of state space, where inputs and outputs are defined, expected, precise, and controllable (Kirsh, 2019). This is because, despite the persistent efforts of cyberneticians and neo-urban science (Batty, 2013), buildings and urban environments are highly complex, unpredictable, and indeterminate, comprising manifold and conflicting forces and phenomena. Because of this, urban and architectural design projects are often described as "ill-structured" or wicked problems.[b] And given the complexity and scale of architecture and urban design projects, that can also entail significant time and cost investment, projects are typically conceived as arrested or static modes of spatial and material organization that reflect but also shape social activities and behavior. However, as Wiberg reflects, "… digital technologies challenge a core idea in architecture—that the physical environment is hard to reconfigure—" (Wiberg, 2017, p. 62).

The complexity, cost, and scale of architectural and urban projects, together with the perception that digital technologies are not within the expertise or scope of architects and urban designers, have shaped a reluctance to see digital technologies as part of the materiality of the built environment and limited alternate approaches to urban technology design more generally. Consequently, scholars reflect that a "critical knowledge gap" exists in the architecture and urban design disciplines in relation to the design of "physical smart environments" (Lee, Ostwald, Kim, & Mi, 2021, p. 1). In comparison to the long established discipline of architecture, the younger fields of HCI and IxD understandably reflect far less path-dependence. Necessarily, HCI and IxD have advanced in step with computing developments and in some cases actively forged new directions. For example, while scientists at the Palo Alto Research Centre (PARC) in the 1990s popularized a vision of a world permeated by un-tethered, miniature, distributed, connected, and embedded computing invisibly and silently calibrating everyday life, computer scientists such as Paul Dourish (2004), Dan O'Sullivan and Tom Igoe (2004) saw opportunities for humans to interact with computers and experience computing in new ways.

3.4 Physical computing

O'Sullivan and Igoe (2004) who defined the notion of "physical computing" in the early 2000s as a system configured to sense, process, compute, and actuate physical change in an environment, believed that computing should expressively interact with humans. They reasoned that physical computing could

b. Following Rittel and Webber (1973) a wicked problem is defined as a problem that is hard to solve because it is characteristically complex and unpredictable. Architectural and urban design problems are seen as 'wicked' as they often involve multiple stakeholders who can hold conflicting and competing views and motivations, meaning that there could be multiple possible design solutions.

create collaborative opportunities for Intelligence Amplification (IA). To mobilize these ideas, they set about creating computing devices that were capable of sensing and responding to people and the environment, arguing that "… we need to think about computers that sense more of your body, serve you in more places and convey physical expression in addition to information" (O'Sullivan & Igoe, 2004, p. xvii).

The ability for a computer to participate in a mutually coherent interaction with a human is typically conceived in HCI as an input-processing-output loop (Suchman, 2007). Yet, as O'Sullivan and Igoe (2004) observe, unlike software system design, physical computing involves "… creating a conversation between the physical world and the virtual world of the computer" (p. xix). For computers to react and respond to physical and environmental phenomena in the world, they require additional hardware and peripherals, namely sensors (transducers) to detect and measure phenomena such as light, temperature, pressure, motion, and vibration. Sensors are also known as transducers because they are devices that convert physical and environmental inputs into electrical signals or digital data so that they can be processed, analyzed, and used by computer systems or other devices to generate outputs. Sensors play a foundational role in capturing and quantifying phenomena in the physical environment, enabling the interaction between humans and machines, and facilitating the functionality of interconnected systems in the IoT paradigm.

For the computer to process sensor inputs and instruct the action of an output i.e., physical actuation such as powering a motor or an LED, instructions need to be written in a programming language that a computer system can understand. A core challenge of implementing a physical computing system is that it involves multiple knowledge domains and skill competencies, including design, engineering, mechanics, programming, computer science, mathematics, and electronics (Vermillion, 2014). In this way, physical computing is also an exemplary interdisciplinary project. For these reasons, and to lower the barriers to engaging with physical computing, Tom Igoe co-founded the open-source electronics prototyping platform Arduino[c] in 2005 at the Interaction Design Institute in Ivrea, Italy.

The Arduino is an open-source microcontroller platform that is optimized to control electronic devices and systems such as sensors, motors, and lights. Its ease of use, relatively low cost, and the large and supportive open-source Arduino community that has grown up around it have made it an accessible and enduringly popular method for non-computer programmers, educators, students, creative professionals, and tinkerers alike to iteratively create and rapidly prototype interaction concepts for physical computing systems. In the HCI community, and for artists, interaction designers and creative technologists the release of the Arduino propelled explorations into ways of interconnecting

c. https://www.arduino.cc.

between physical and digital realms. Core ideas that shaped these endeavors centered around opportunities to give digital information physical expression, to materialize interaction, and to shift away from conventional computing interfaces. HCI and IxD research groups and communities in the United States, the Netherlands, and Italy led early efforts to theorize and design approaches to embodied interaction. A core objective was to challenge the dominant paradigm for interacting with computers by engaging with a wider spectrum of human senses as forms of input into human-computer exchanges. These efforts have been variously referred to as rich interaction, tangible computing, physical computing, natural user interfaces, tangible interactions and "augmented physicality" (Benyon, 2014; Dourish, 2004; Hornecker, 2011; Ishii & Ullmer, 1998; Koskinen, 2011; Zimmerman & Forlizzi, 2014).

Significantly, the embrace of physical computing in the IxD community served to set it apart from its HCI origins. With the foundational theories and methods of HCI and IxD grounded in information systems design, to support the engagement with interactive environments IxD scholars began to embrace socio-spatial theories such as proxemics (Hall, 1966, 1968) and perspectives from human geography and architecture (Benyon, 2014; Dourish, 2004; Harrison & Dourish, 1996). More specifically, Dourish refers to the notion of "social computing" as HCI's effort to, "… incorporate understandings of the social world into interactive systems" (Dourish, 2004, p. 16). Equally, to help explain ways of thinking and knowing through bodily action IxD scholars replaced cognitive science theories more commonly used in HCI, with theories such as ecological psychology (Gibson, 1986). Tamie Glass (2018) describes this as a shift from interface design to interaction design and from a functional focus on how "… people intuitively determine how to use something", to an emphasis on the experience of "…dynamic exchange[s] between people and systems" (p. 13).

Still, shifting scales from the design of interactive screens, objects, and wearables, to interactive environments has been a challenging feat for fields grounded in information systems design, programming models, and human- and user-centered design methods. Nonetheless, the urban environment has become a popular focus for interaction designers with scholars in the field declaring urban interaction design (UIxD) as a new interdisciplinary approach to the design of urban space integrated with sensor-based technologies and computational systems (Brynskov et al., 2014; Zaffiro, Bracuto, Brynskov, & Smyth, 2015). UIxD has taken shape in the form of temporary installations and research projects that have examined ways of integrating digital technology and digital media into urban environments, and particularly in relation to social and civic goals (De Waal & De Lange, 2019; Foth, Tomitsch, Satchell, & Haeusler, 2015; Hespanhol et al., 2017). Yet, even as UIxD has gained traction, IxD, user experience, and service design expertise remain predominantly oriented to the creation of websites, mobile apps, and "urban applications" (Tomitsch, 2018).

3.5 The *Ubiquitous Cities* design studio

Digital technologies are by now a pervasive feature of the built and urban environment and everyday life, yet the knowledge and skills required to integrate digital technologies into urban space and to create responsive and interactive environments remains outside of most architects' and urban designers' skillsets (Lee et al., 2021; Vermillion, 2014).

Consequently, in the *Ubiquitous Cities* course in the CoDe program urban technology is conceptualized as a dynamic entanglement of digital and physical-material worlds, where software applications, programming languages, and electronics are not imposed on the urban environment but are seen as constitutive materials of the design situation. Digital technologies and computational systems are further seen as opportunities to stimulate creativity and to animate critical and ethical inquiry.

The *Ubiquitous Cities* course adopts and adapts a model of learning that has long been central to architecture and design education, namely, the design studio (Schön, 1985). Design studios differ from traditional instruction-based learning models that typically centralize explicit description. By contrast, the design studio is informed by the constructivist principles and a learner-centered approach that advances modes of "learning by doing". To this end, design studios typically adopt a project-based learning model as a mode of experiential learning. In project-based learning environments, students are presented with a complex and authentic problems that are grounded in real-world settings and parameters and that can have potentially manifold solutions and possibilities for exploration. As such while the objective of the *Ubiquitous Cities* course is to design and prototype responsive and interactive spatial environments that involves configuring and programming a physical computing system, the first task is to understand the spatial, social, organizational, and material complexities of given real-world sites and to identify problems and opportunities.

To adapt the traditional architectural and urban design studio, the *Ubiquitous Cities* course adopts a tripartite, cross-scale design framework that draws on the tenets of multi-level analysis and interconnection that are central to transitions thinking, transition management, and transition design perspectives (Geels, 2005; Irwin, 2015, 2020; Loorbach, 2009). Grounded in complex systems theory and systems thinking, transitions concepts and frameworks emphasize processes of shifting between system levels to bring leverage points and pathways for problem-solving in a complex problem space into view (Irwin, 2020, p. 44). The course is structured to shift through three core and interrelated scales of thinking and designing. This includes at the macro-scale an overview of smart city visions and initiatives, at the meso-scale an examination of urban social and spatial conditions, and at the micro-scale an engagement with interaction concepts through design and prototyping (Fig. 3.1).

As a process of scaling that from a realist scale perspective infers shifting between states or levels that are comparatively different in magnification,

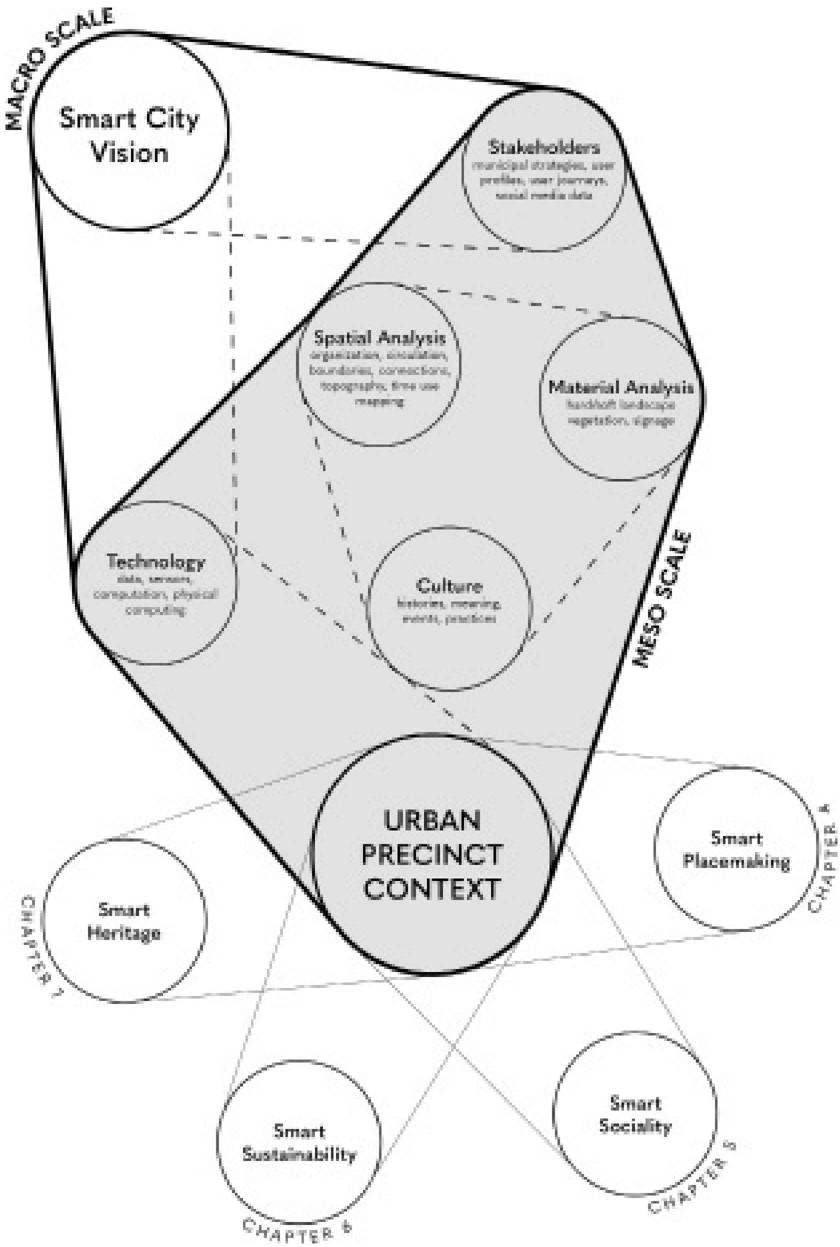

FIG. 3.1 The *Ubiquitous Cities* cross-scale design framework. *(Credit: By Author.)*

extent, or resolution (Manson, 2008), the cross-scale framework aims to bring into view different perspectives, phenomena, conditions, and parameters. Moreover, as the *Ubiquitous Cities* course advances the view that urban problems can be understood as local problems and vice versa, it enacts a scaling of the smart city and translates the overarching aims but also technologies of the smart city to suit and serve the local. In short, scaling between macro, meso, and micro levels of design aims to connect the goals of the smart city, which include its vision for sustainable, equitable, and livable cities, to institutional and organizational stakeholder policy objectives (meso), and to local scale and everyday phenomena and conditions to generate urban technology design projects (Fig. 3.1).

Scale 1 The Macro Scale: The Smart City Vision

To understand and critique the goals of the smart city vision, the course begins with a desktop case study of an "actually existing" (implemented) and/or proposed smart city strategy. By presenting smart city case studies in class, students compare and comprehend their strategic similarities, but also vast differences in how neighborhoods, cities, and regions prefer and adopt some smart city initiatives and urban technologies over others. This aims to demonstrate how the global smart city vision is refracted, rescaled, and localized through the political economies of nations and municipalities.

Scale 2 The Meso Scale: Stakeholders and Urban Space

The second scale of thinking explored in the *Ubiquitous Cities* course addresses how goals of the smart city can be mapped to an urban precinct or local scale. To this end, and following a project-based approach, students engage with real-world sites and stakeholders. Since 2015 urban precinct sites have been identified in local government areas (LGA) around Sydney, New South Wales (NSW) Australia. This has included in the Willoughby (LGA) (2015), the Parramatta LGA (2016), the North Sydney LGA (2020) and the UNSW Randwick campus (2017, 2018, 2021 and 2022). During the design research stage project site stakeholders have been directly engaged in the process by presenting to students. This has included presentations by the Mayor of Willoughby City Council, Gail Giles-Gidney (2015), the Head of the Future City, Geoff King from the City of Parramatta (2016), UNSW Estate Management representative Niki Douglas (2017/18), and Mayor of North Sydney Council Jilly Gibson (2020). Following these presentations, students have undertaken further desktop research, including sourcing relevant grey literature such as municipal smart city strategies and action plans as well as conducting *in-situ* design research of their allocated urban precinct sites to inform a "problem definition framework".

The range of data collected during the design research stage includes historic records, photographs and narratives, spatial and material documentation of the site, observational time-use data about activities and site use, as well as social media data to present a rich picture of the urban precinct as a "place" not simply a space. Students record and map key spatial and organizational characteristics of their site, including solar orientation, edges, bounding buildings and/or urban objects, primary and secondary entry and exit points and topographic features. They also use dynamic and time-based mapping techniques to develop knowledge of time-use patterns and social behavior. Additionally, to unobtrusively explore sentiment insights and better understand the perspectives of the precinct's various stakeholders, students search social media databases, where available and relevant, other forms of statistical census data.

Based on these collected design research data, students create user personas. User personas are a common technique adopted in user experience (UX) design to foster empathy for stakeholders and inform the core aims or goals of the design project. Students use site observations and other data to create fictional and composite characters to represent a diverse range of stakeholders. Writing user personas is a useful way to think through the needs, experiences, behaviors, and goals of human, but also n*on-humans* in relation to the design site. In recent years, and in response to *post-userism* and calls to de-center humans and recognize the agency of non-humans and things in the design process, students have also created non-human personas relevant to their urban precincts including trees, lawns, bins, ibis birds, and dogs. User personas are typically written as a scenario or a narrative that is focused on how an individual user or group might work towards a goal or confront a friction point or series of challenges in a particular context. User personas thereby aid designers to connect the dots between human/non-human goals and behaviors and design problems and opportunities.

3.6 Problem definition framework

To draw out more specific issues and opportunities relevant to their urban precinct sites students in the *Ubiquitous Cities* course are required to synthesize and problematize their design research. Design problematization refers to a process of discovery that aims to identify, reason, frame, and define problems or opportunities based on gathered data to formulate proto-goals and aims for a design project. A problem definition framework is a synthesis or assemblage of the design research analysis and site research. In the *Ubiquitous Cities* course the problem definition framework is organized to connect the overarching objectives of relevant municipal smart city visions to local-scale conditions and issues and align them to a selection of urban technology precedents to establish and define a proto-design solution space.

Scale 3 The Micro Scale: Behaviors and Interactions

The third scale of design thinking zooms in on the spatial and human-technology or life-technology interaction scale. Having established a problem definition framework that identifies core objectives and a proto-design solution space, the students explore how interaction concepts can be realized through the integration of physical and digital elements. Design problems are rarely given or complete, rather "problems" and "solutions" are created by designers from the materials of the "design situation" and are continuously reshaped or reframed during the activity of designing and as new information comes to light (Harfield, 2007; Schön, 2016). It is in this sense, that design problems and solutions are argued to co-evolve. The process of iterative design and prototyping involves students developing and applying basic skills in Arduino programming to test systems and interaction concepts in ways that can also reshape the design problem and solution space.

3.7 Urban technology prototyping

Urban technology prototyping is a productive way to explore and test cyber-physical systems across a range of scales, including at the scale of human-technology interactions. In the *Ubiquitous Cities* course, basic electronics programming is taught alongside the spatial and material analysis of allocated real-world urban precinct sites. Physical prototyping is engaged as a way to learn about cyber-physical systems as well as fundamental electronics concepts, including the basics of circuits, current flow, ground and voltage, polarity, and Ohm's law. Programming a microcontroller (Arduino or other) and connecting various electronic components provides a *tangible* way to develop electronics knowledge. Equally, prototyping is a productive way to understand the concept of a cyber-physical system that includes sensor inputs (data collection), programming instructions for outputs (data processing) and outputs (in/tangible actuation) (Fig. 3.2).

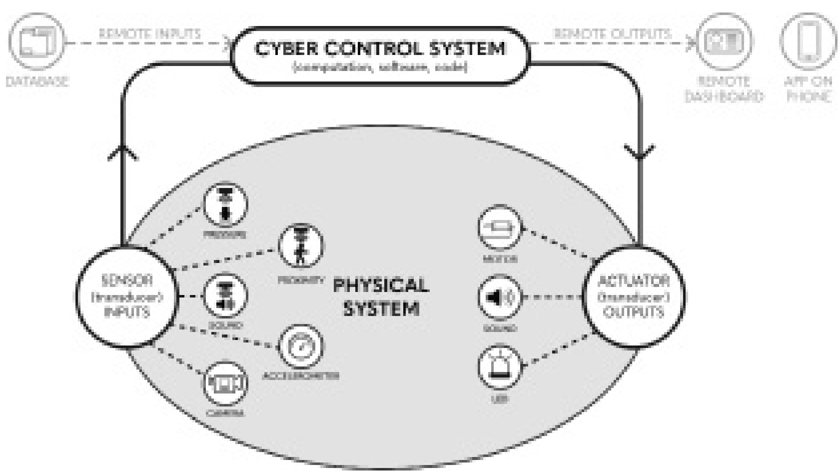

FIG. 3.2 Cyber-physical system diagram that connects physical components and computational elements using sensors and actuators. *(Credit: By Author.)*

TABLE 3.1 Interaction concept definitions.

Interaction concept	Definition	Expression
Active	The system responds to specific input in a pre-defined way (i.e., switching system on or off)	→
Reactive	The system adapts its response depending on user input and/or in response to changes in the environment in a pre-defined way	→ ←
Interactive	The system requires bidirectional communication and collaboration between the system and user input to drive the experience based on pre-defined programming that can result in a wide range of experiences	→ ← →
Generative	The system responds to user input and autonomously and actively contributes to the creation and generation of the system outputs to co-create the experience	→ ← → →→←

Credit: By Author.

Building basic cyber-physical systems that integrate physical components and computational elements using sensors and actuators provides a further way to explore physical computing principles and different interaction states and schemas (Table 3.1). To develop knowledge of interaction principles to inform the design of interaction schemas for specific urban precinct sites, students also draw on and analyze a range of urban technology precedents. To analyze and explain existing urban interaction design projects, students draw on the categories of interaction states as described in Table 3.1.

In user centered design fields such as UX, HCI, IxD and product design, prototyping is a common method to test design concepts. Prototypes are used as dynamic tools throughout the design process to refine design problems evaluate design ideas or establish a proof-of-concept. Prototypes are seen as particularly critical for information systems design and projects that use digital technologies as a process to test and debug technical solutions. Prototypes can be low or high fidelity and can be rapidly and iteratively produced as a serial technique to enhance the precision of a design system. In engineering, prototyping is an important part of the process of technology validation and facilitates an iterative mode of "scaling up to practice". For example, "…the inventors of the jet engine validated their designs by building increasingly realistic prototypes and testing them in increasingly realistic environments" (Wieringa, 2013, p. 20). Physically prototyping urban technology projects enables stakeholders and designers to test and explore the relationships between computational,

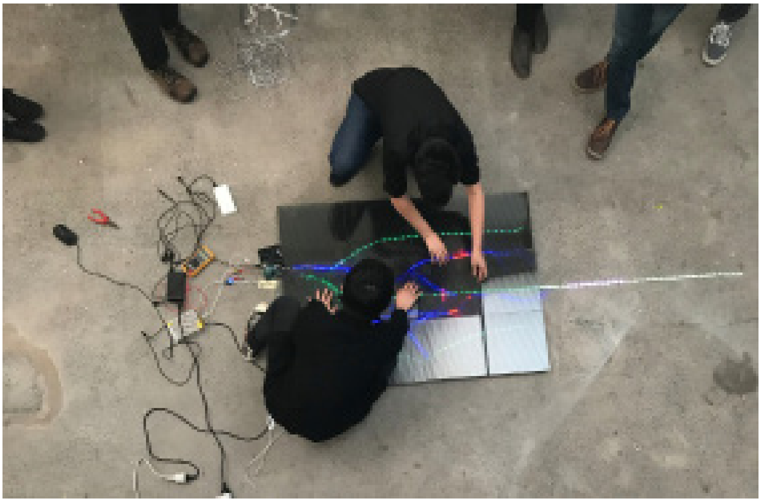

FIG. 3.3 Assembling an urban technology prototype using an Arduino microcontroller in the *Ubiquitous Cities* design studio in 2018. *(Credit: By Author.)*

material, and physical elements (Fig. 3.3). Furthermore, iterative prototyping provides a tangible way to understand how a project's "… performance relate[s] to materials, weight, scale, forces, and movement" (Vermillion, 2014, p. 456). According to Joshua Vermillion (2014) physical prototyping accelerates student learning as they must apply and coordinate a range of technical skills and concepts.

The Arduino platform was specifically developed to prototype interaction concepts. This is achieved by developing "sketches", or code written in the Arduino Integrated Development Environment (IDE) or Arduino software (based on the computer programming language C++). To execute an interactive schema, the code is uploaded to Arduino microcontroller hardware that relays instructions to connected sensors and actuators. The process of installing software on a small read-only memory chip such as the Arduino Uno is also referred to as "firmware" programming. Firmware is a form of software that provides basic machine instructions to enable forms of hardware (such as sensors) to function and communicate. While the Arduino Uno is a helpful platform for learning about the foundational concepts of a cyber-physical system, IoT, physical computing, and interaction states, it is also base model that operates with limited processing power and memory resources. In the *Ubiquitous Cities* course to date, most prototypes have been tethered to an Arduino, that is, they have been hard wired. However, where projects have configured systems to send data over a network such as through Wi-Fi communication, or a project has included multiple actions and required parallel coding, other microcontroller boards have been used such as the Arduino Yún (Fig. 3.4) or small single-board computers such as the Raspberry Pi.

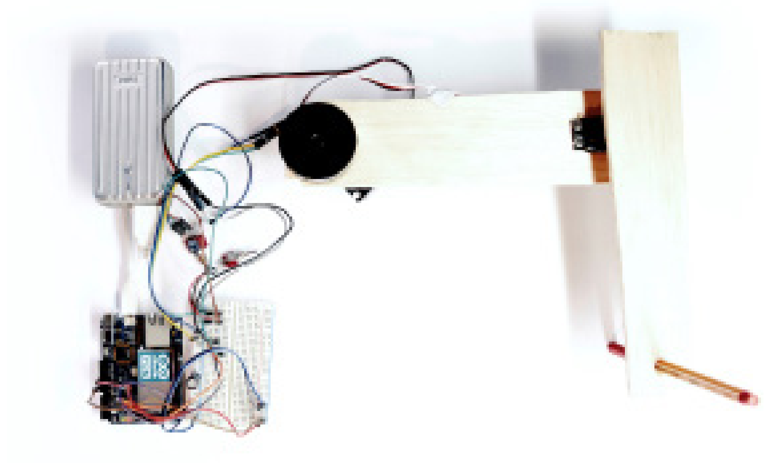

FIG. 3.4 Final prototype for *Urban Scribe by* Jake Coppinger in the *Ubiquitous Cities* design studio in 2016. *(Credit: Jake Coppinger.)*

By creating physical, working prototypes students confront key challenges that come with the entanglement of digital and physical processes and materials. Through iterative prototyping they build their understanding of the relationships between spatial organization, material properties, environmental forces, system performance, as well as the experiential qualities of interacting with computing. For example, by adjusting the positioning of sensors and the speed of a servo motor students learn how spatial organization, timing, and mechanical actuation can impact what can be sensed, interaction possibilities, and experience. They appreciate how cyber-physical systems even at a small scale, involve the coordination of inputs, processes, material elements, and outputs. It is in this sense that sensor-based technologies and programming are truly understood as materials of the design situation (Schön, 1992).

At the culmination of the course, students build a working, albeit almost always scaled prototype of their urban technology project. Principally these prototypes aim to demonstrate the project's basic interaction concept but also the student's ability to program a microcontroller to sense phenomena in an environment and drive responsive actuation. Given the extrapersonal scale or size of an urban precinct as a design site, the short time frame of the course, as well as the requirement to communicate the urban technology project in a variety of ways, including through visualization methods, full-size prototypes are neither feasible nor essential. Instead, urban technology prototypes are created at a scale that best aids the communication of the project's design intent and its interaction concept. To this end, where necessary students are encouraged to adopt "Wizard-of-Oz" style prototyping that refers to a technique of simulating the function and behavior of a system to explore and communicate its core

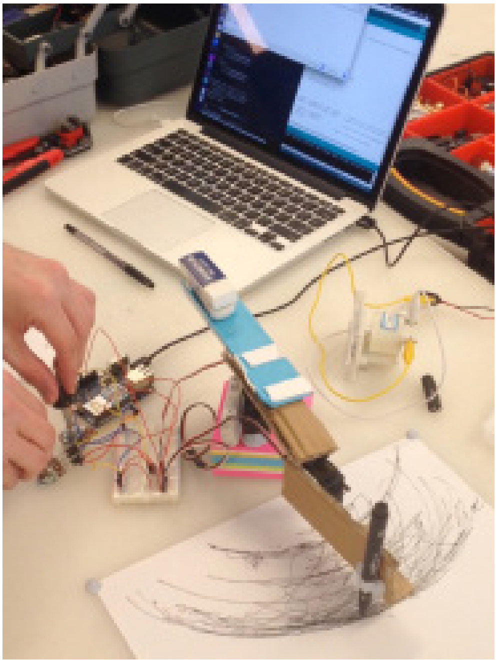

FIG. 3.5 Iterative prototype for *Urban Scribe* by Jake Coppinger in the *Ubiquitous Cities* design studio in 2016. *(Credit: By Author.)*

interactive characteristics by manually controlling the system behind the scenes (Fig. 3.5).

Wizard-of-Oz style prototyping is a valuable technique as it allows designers to rapidly test and evaluate interaction concepts without committing to a technical system design. Where time permits multiple rounds of iterative prototyping, a project's design intent can be progressively tested and refined in relation to a range of possible technical system configurations. For example, in the speculative urban technology project *Residue* designed by Charlotte Firth and Matthew Trilsbeck in 2016 for a site in Parramatta, Sydney, Australia, a scaled prototype mimicked motion detection by using a photoresistor sensor input to trigger the illumination of an orb containing LEDs (Figs 3.6, 3.7). However, in a real-world setting the project could collect situated data to drive the system in several ways and by using different sensors, such as either a passive infrared (PIR) sensor or video cameras combined with computer vision methods. The decision to adopt one technical system design over another will hinge on specific conditions of the context, as well as budget and operational requirements. Factors to consider could include local microclimate conditions, power access and consumption, application range, size, security risks, data retention requirements, data privacy risks, regulatory compliance, and maintenance access requirements.

FIG. 3.6 Scale model prototype of *Residue* by Charlotte Firth and Matthew Trilsbeck in the *Ubiquitous Cities* design studio in 2016. *(Credit: By Author.)*

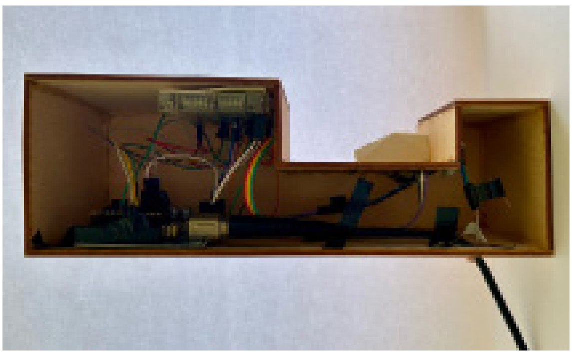

FIG. 3.7 Electronics concealed in the scale model prototype of *Residue* by Charlotte Firth and Matthew Trilsbeck in the *Ubiquitous Cities* design studio in 2016. *(Credit: By Author.)*

While the Arduino platform is an accessible tool for learning, experimenting, and prototyping sensor-based interaction, Arduino components are also used in real-world IoT products and cyber-physical systems. For example, in response to the COVID-19 pandemic and the growing demand for air quality monitoring in workplaces, the Arduino Team developed an environmental monitoring product.[d] The Arduino environmental monitoring product is significant here for several reasons. Firstly, the product highlights how Arduino hardware and software can be used to create real-world IoT products. Secondly, it

d. https://blog.arduino.cc/2022/10/20/environmental-monitoring-of-corporate-offices-with-arduino-pro/.

demonstrates how ethical concerns related to data security and privacy can be addressed through hardware and software system configuration.

The product's Arduino Pro ecosystem includes "IoT node" hardware that integrates environmental sensors to collect air quality, temperature, and humidity data. It also uses a video camera to collect occupancy data. To address security and privacy risks associated to the use of video camera data, the data pipeline design involves feeding the video camera data to a local IoT node that uses computer vision and machine learning techniques (called TinyML) to generate occupancy counts from the video stream. This demonstrates the computer science method of "edge computing" which refers to instances where data is processed and analyzed "on-the-edge" of a network or device such as a sensor, or in this case, an IoT node. In short, this means that data is processed close to the source of its generation in ways that can mitigate the risks associated to data transmission pipeline insecurity. In the case of Arduino Pro ecosystem, video data is sent from the video camera to the IoT node for processing such that the data relayed to a gateway cloud server and remote dashboard application is not video data, but rather numerical data that relates to the quantity of people detected.

Psychophysical studies show attention is a To illustrate, let us consider the passive distribution of K+ ions in the squid giant axon as studied by Hodgkin and Huxley. ence of a single area called SII.

$$E_K = 58.2 \log_{10}\left(20/400\right) = -76\,mV \tag{1.1}$$

Anatomical studies in humans suggest there are also four separate regions called OP1-OP4, yet how the human studies axon by the Nernst equation as such:

$$\sum r_{Gi} \times V_G$$

Taken collectively, the urban technology design prototypes created during the *Ubiquitous Cities* courses occupy a middle ground somewhere between a sociotechnical thought experiment and the real world. Put another way, they are "provocatypes" (Bowles, 2020) that aim to stimulate moral imagination, uncover unintended consequences and externalities, surface ethical concerns, and suggest other forms of urban life that can and should be lived with technology.[e] Notably, as Bowles (2020) reflects, a provocatype isn't always "good design", nor resolved design, rather it is design that aims to suggest something otherwise (p. 24).

Over the course of its 8-year run, the *Ubiquitous Cities* design studio has examined real-world urban technology examples to guide students in the creation of their own speculative urban technology design projects (Fig. 3.8). A

e. The concept of "provotyping" has origins in information systems design in the 1990s, and is described as a method to prompt discussion with users. Provotypes were devised as deliberately provocative prototypes to illicit user feedback (Boer & Donovan, 2012, p. 389).

selection of these projects is included in the following chapters of this book. The included projects are organized around four core themes including urban activation and placemaking, with sub-themes of safety, security, and amenitization; social engagement, with sub-themes of interaction and play; sustainable behaviors, with subthemes of nudging and agency, and cultural heritage. These four overarching themes further organize the following chapters of this book. Within each chapter and to illustrate how spatial design, interaction concepts, sensor-based technology, and physical computing come together, urban technology projects and speculative design examples are categorized according to interaction states and diagrammed as cyber-physical system configurations.

3.8 Conclusion

Usman Haque observes that while the goals of the smart city are commonly oriented to notions of efficiency, optimization, predictability, convenience, and security, "… these things make a city bearable, but they don't make a city valuable" (Haque quoted in Poole, 2014). Design education provides an important context to explore alternate sociotechnical visions for future smart cities and to shape new designers who possess integrated skills in spatial design thinking, computational thinking, and moral imagination. The *Ubiquitous Cities* design studio has set out to challenge the conventional idea of the smart city as a large-scale, invisible, unobtrusive, and extractive model of digital technology and urban space integration by exploring alternate models that prioritize the local-scale and leverage the affordances of physical computing and interaction. In the following chapters of this book, urban technology case examples, and speculative urban technology design projects created during the *Ubiquitous Cities* course are construed as provocatypes to materialize alternate sociotechnical visions and prompt philosophical and ethical inquiry.

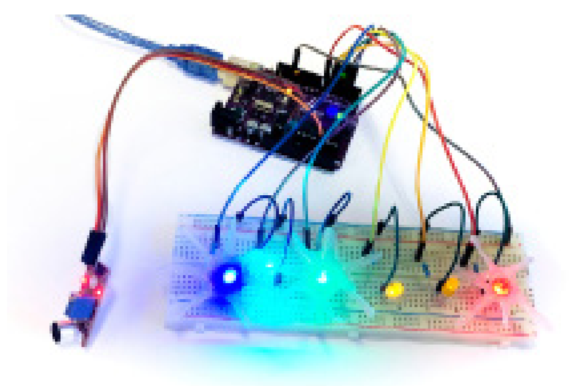

FIG. 3.8 *Colourised Neurons* urban technology prototype by Orchha Pheap, from the *Ubiquitous Cities* design studio, 2022. *(Credit: By Author.)*

TABLE 25.1 Summary of primary afferent fibers and their roles.

Modality	Receptor	Table straddle head		
		Fiber type	Velocity ($m\ s^{-1}$)	Role in perception
Thermoreception	Meissner corpuscle	Ab	42–72	Flutter, motion
	Ruffini corpuscle	Ab	42–72	Unknown, skin stretch
	Pacinian corpuscle	Ab	42–72	Vibration
Thermoreception	Bare nerve endings	C	0.5–1.2	Warmth
	Bare nerve endings	Ad	12–36	Cold
Nociception[a]	Bare nerve endings	Ad	12–36	Sharp pain
	Bare nerve endings	C	0.5–1.2	Burning pain
Table header top level				
Mechanoreception	Merkel cell	Ab	42–72	Pressure, form, texture
Nociception	Bare nerve endings	Ad	12–36	Sharp pain
Nociception	Bare nerve endings	Ad	12–36	Sharp pain
Table one head				
Thermoreception	Bare nerve endings	C	0.5–1.2	Warmth
	Ruffini corpuscle	Ab	42–72	Unknown, skin stretch
	Bare nerve endings	Ad	12–36	Cold

The colours in this table are shown in various cell entry layouts. These layouts demonstrate the various possibilities of CALS tables and of the extensions to CALS tables.

[a] *Table ftnote to go in here, set across full table width.*
Source: Table credit to go in here, set across full table width, table legend to go in here, set across full table width.

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