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Adaptive Architecture and Personal Data

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1. ABSTRACT

Through sensors carried by people and sensors embedded in the environment, personal data is being processed to try to understand activity patterns and people's internal states in the context of human-building interaction. This data is used to actuate adaptive buildings to make them more comfortable, convenient, and accessible or information rich. In a series of envisioning workshops, we queried the future relationships between people, personal data and the built environment, when there are no technical limits to the availability of personal data to buildings. Our analysis of created designs and user experience fictions allows us to contribute a systematic exposition of the emerging design space for adaptive architecture that draws on personal data. This is being situated within the context of the new European information privacy legislation, the EU General Data Protection Regulation 2016 (GDPR). Drawing on the tension space analysis method, we conclude with the illustration of the tensions in the temporal, spatial and inhabitation-related relationships of personal data and adaptive buildings, re-usable for the navigation of the emerging, complex issues by future designers.

2. INTRODUCTION

In future, all data about people, everything that can be sensed about them, will be made available to the technical infrastructure of buildings. While this might be conjecture, the rapid and often unchecked developments of the Internet of Things, the smart home and of smart cities around us are pointing undoubtedly in that direction, especially if one considers this from a merely technical standpoint. Thrift characterises this with the term 'qualculation', describing how everything, everyone and everywhere are becoming addressable [1]. Data about people in this context includes, for example, people's locations, movements, body and facial expressions, physiological activity including brain activity and any interpreted states that can be derived from those. However, the technical challenges, especially for the latter, remain admittedly very substantial.

Increasingly, everyday mundane buildings have aspects of this form of data usage, from eco-focused offices [2] to eco-friendly homes [3]. There have also been efforts to integrate diverse unrelated systems in the existing building stock through IoT technologies, to produce more meaningful data analysis across systems [4]. In addition, there is experimentation with the use of data about people in the built environment in architecture schools [5], HCI research labs [6] and by artists [7]. Further, data is being discussed in the architectural community as another (new) building component [8] and as an invisible detail in the design and construction of architecture [9]. On a city level, personal data is being used to both gather information about the city and its citizens as well as to create interventions to improve city life, as for example, described and discussed in [10] and [11].

These developments are broadly underpinned by a vision, perpetuated by technology researchers amongst the pervasive computing and ambient intelligence communities, originally framed by Weiser's concept of ubiquitous and calm computing [12, 13]. The influence of Weiser's ideas can be seen in Architecture early on in the concept of Cooperative Buildings, focussing on seamless collaborative work connecting individuals and groups, and the virtual and the physical [14]. In the CS community, a focus on ambient intelligence (AmI) emerged, bringing together sensor networks, pervasive computing and artificial intelligence, and promising that environments become sensitive to people in an intelligent way [15].

Despite the early enthusiasm about the above technologies, multiple angles of critique have emerged. McCullough emphasized how critically important specific places remain for our interactions through digital technologies, moving away from uniform interaction designs that work everywhere [16]. Similar to McCullough, Rogers proposed a focus on using pervasive computing to engage people with what they are currently doing, instead of calm computing disappearing into the background [17]. Bell and Dourish argue that Weiser has not accounted for the messiness of the real world, which does not revolve around efficiency [18]. In Everyware, Greenfield reflects how pervasive computing is seen from the outside of the research community and proposes a number of concerns and guidelines around the privacy, surveillance and regulation in response [19]. There has also been recurring criticism of the top-down nature of smart cities and ambient intelligence as for example discussed in [20]. Preceding this by decades, the author J.G. Ballard sketched out a dystopian future in which a home's inhabitants must contend with its learnt adaptations, still responding to the psychological states of previous owners, very much a competing past future vision to Weiser's calm computing [21].

The research presented in this paper aims to address this space afresh by asking: *What are the possible outcomes of this emerging integration of people's behaviour, data about people, and adaptive architecture?* In what follows, we sketch out the broad background to this work, introduce our future envisioning approach and present results from three iteratively developed workshops, before reflecting on these results. Uniquely, this reflection brings together our analysis of the relationship of personal data and Adaptive Architecture with a contextualisation within the current ethical and legal context of data protection governance. We conclude by presenting the tensions in the temporal, spatial and inhabitation-related relationships of personal data and adaptive buildings through tension space analysis [22], re-usable for the navigation of these complex issues by future architects and user experience designers.

Ecology of Built Environments

Given the premise that data about people will be pervasively available to our built environments, what does 'built environment' really refer to in this context? With reference to the idea that buildings are the recipients of personal data, what is it that data is really available to?

Architecture has already moved away from being considered a static artefact to something that is seen as adaptive to a building's surroundings and its inhabitants [23]. Conceptually, this definition incorporates research and practice projects that are described as reactive, responsive [24], interactive [25], robotic [26] and smart [27]. Going beyond entirely manual architectural adaptivity as for example introduced by Rietveld [28], computing is now playing a part in most new commercial buildings, integrating environmental and people focused sensing, software infrastructures and actuation technologies (such as building management systems). Using a variety of examples such as airports and supermarkets, this integration of software with (building) hardware of everyday life has been outlined in [11]. Outside technology being embedded within buildings, inhabitants also bring their own data-rich, mobile computing and IoT devices, locate them in space (e.g. voice controlled hubs, controllable light bulbs or smart TVs) or wear them on their bodies (e.g. fitness trackers, mobile phones), framed in turn by considerations about the 'quantified self' [29]. Furthermore, buildings are part of the smart urban environment, providing another layer of information technology on a much larger scale. In this context, concerns have been raised about the digital layer superseding the physical layer of the city, thereby negatively affecting the human experience in cities [30]. Further reflection on the values underpinning smart city deployments and how they can meet citizen needs is necessary [31, 32]. Furthermore, the raft of privacy and security risks surfaced by the convergence of IoT, big data and cloud computing need to be managed effectively [33].

For the context of this paper, we envision adaptive built environments as ecologies of IoT devices and furniture, adaptive architecture (smart homes, intelligent office buildings) and the smart city, technically and interactionally fully integrated. Similar to what Papadopoulou et al propose, inhabitants would then have continuous access to services, via the relevant part of the overall ecology, depending on the position of each and every inhabitant [34].

Inhabiting Adaptive Architecture

Despite the fact that no such full integration currently exists anywhere, we are clearly seeing parts of this integrated ecology emerging. Furthermore, whilst they are emerging, we already inhabit them. This is where there is a key difference between considering interaction with artefacts and inhabitation of places. As we are always somewhere, we always inhabit 'a' place, whilst we can also avoid certain places. As technology integrations grow around us, more and more of the places we can inhabit are part of the computationally adaptive built environment ecology. These offer implicit and explicit means of interaction in which we are sometimes participating simply because of being there (e.g. face recognition, number plate recognition, occupation counter, key card logs). Quite in contrast to choosing to pick up an interactive artefact, we have fewer interactional choices in digitally augmented and 'sensorised' places, while Marx traces the possible measure that could be offered in resistance [35]. However, even if the multiple layers of adaptive architecture ecologies are all magically integrated and interoperable, it remains the case that we mostly interact with a relevant part of it, the part that surrounds us and is therefore 'to hand'. Regardless of whether adaptive ecologies are fully integrated or not, we would like to argue that only a given sub-element, that which surrounds people and is close by, is relevant for interaction and agree with Steenson who argues for this concentration on this meso-scale of the built environment spectrum [36] as well as Addington who calls for a focus on discrete and, more importantly, meaningful interactions when designing in this space [37].

Applications and Prototypes

Across this evolving adaptive ecology, a sprawling variety of applications have been proposed. Pervasive healthcare suggests continuous, embedded health monitoring of people wherever they are [38]. Smart lifts combine data from card readers and destination selections to create more efficient circulation and to provide occupancy information [39]. Urban lighting is developed to create light patterns depending on the presence of people [40] and the Open Columns prototype disperses people when indoor $C0_2$ levels had reached certain levels [41]. The Ada space draws on vision, sounds and touch detection to enable playful interactions between multiple inhabitants and multiple parts of the same room [42]. ExoBuilding both kinetically responds in real time to the breathing behaviour of its inhabitants [43] and used that same physiological data to manipulate the breathing frequency of its inhabitants [44]. Finally, the same infrastructure that makes such spaces adaptive through data about people can also deliver very important information about how such spaces are used and for activity recognition [45]. This infrastructure also enables extended post-occupancy evaluation methodologies as described by Lau [46]. For a still growing list of examples in this adaptive architecture space, the reader is referred to [47].

Many of the proposed applications and prototypes remain discrete. Inhabitants interact with those when they are faced with them in spatially and temporally contained episodes. Implementations of fully integrated systems are difficult, not just technically, but also because so many different stakeholders are involved. There is, however, much conceptual work on this integration as in the already mentioned pervasive healthcare work [38] or for example concepts to bring personalised architectural responses to hotel occupants [48]. In the broad context of AmI work, these seek to integrate episodic interactions into something larger and to create longer-term interactions independent from episodes.

Alongside the rapidly growing developments in adaptive architecture, the criticisms are also growing. Wilson et al review recent smart home developments and report that a concerted focus on inhabitant needs is still missing [49], repeating Harper's much earlier critique [27]. Addington laments the technology push that is still prevalent and calls for the design of meaningful interactions in architecture [37] as does Aarts in the context of the Ambient Intelligence community [20]. The wider threats to safety and privacy of the full integration of those developments are discussed in Ahonen [50], which sits in the broader context of architecture playing a role in social control [51, 52]. Crime prevention through environmental design (CPTED) seeks to manage opportunities for criminal acts to occur through building design [53]. This might for example involve increasing visibility of walkways in housing developments through better use of natural and artificial lighting. Within surveillance studies, increased surveillance of public space has been a longstanding focus, from questioning the efficacy of early CCTV in different urban spaces such as car parks [54] to concerns about smart CCTV using facial and gait recognition to survey train stations or subways [55].

Whilst the legal rights of users need to be made manifest and responded to, the desired ways for living in digitally mediated urban environments need further reflection. As Kitchin argues in the context of smart cities, *"the realities of implementation are messier and more complex than the marketing hype of corporations or city managers portrays and there are a number of social, political, ethical and legal concerns with respect to the kind of society smart city initiatives seek to create"* [56]. At the more dystopian end of the spectrum, again within surveillance studies, there is particular concern about the links between smart cities, increased surveillance and militarisation of urban space. Here, citizens' human rights are negatively impacted by increased control and monitoring of public space [57]. As Graham states, we have entered an era of militarized urbanism guided, in part, by targeting of individuals enabled by new information technologies for security management: "*… this latest doctrine stresses that means must be found of automatically identifying and targeting threatening people and circulations in advance of their materialization …*" [58, p.385]. In response to these wider concerns Jones et al proposed an people-centred, ethical framework for the further development of intelligent environments [59]. In other words, in realising socially sustainable interactions with adaptive architecture, we need to be wary of the social, ethical and legal risks at play, and ask what kind of future we seek to build.

Personal Data

Data about people, providing information about their activities and behaviours, is at the heart of the adaptive architecture ecologies outlined here. This data is the technical glue that binds such ecologies together. Sensors embedded in the environment typically owned by groups of people (families, private and public organisations) produce data alongside mobile devices carried and owned by individuals. Data about people in particular places is automatically collected by deployed infrastructures and people actively provide information voluntarily by using location-tracked social media or fitness trackers, for example. Finally, previously archived sets of personal data can be available to buildings, such as the records kept by a city's administration or for example a health insurance provider. Data from multiple sources is then integrated. The resulting combined data sets can be mined to recognise the activities of individuals and groups of people [60] and it can be used to compute information about people's psychological states [61].

Definition

Personal data is a strictly defined legal concept within European Data Protection (DP) law. The pre-internet, European Union (EU) Data Protection Directive (DPD) 1995 has regulated personal data processing across the European Union for over 20 years. However, the rules and principles have been updated for an age of ubiquitous computing. In 2016 its replacement, the EU General Data Protection Regulation (GDPR), was passed and has been enforced across the EU from May 2018. Within GDPR, the nature of personal data is broad and all encompassing. It includes any information relating to an identified or identifiable natural person, i.e. the 'data subject' (Art 4(1) GDPR). Their identification can be direct or indirect through use of more obvious attributes like name, location data or ID number to a combination of factors linked to their physical, physiological, genetic, mental, economic, cultural or social identity (Art 4(1) GDPR). Once its established personal data is being processed, the entire GDPR framework applies.

Beyond 'standard' personal data, the law around data handling becomes more complicated when 'special categories' of personal data are being processed (Art 9, GDPR). These more sensitive types of information relate to health, sexual orientation, race, religion, political or philosophical beliefs, to name a few. Given the scope for harm if not handled properly, biometric data is now included as a special category of data. It is legally defined as '*personal data resulting from specific technical processing relating to the physical, physiological or behavioural characteristics of a natural person, which allow or confirm the unique identification of that natural person, such as facial images or dactyloscopic data*' (Art 4(14), GDPR). This is particularly relevant for adaptive applications reliant on affective computing approaches and biofeedback from occupants.

Any processing of personal data must rest on one of the six provided legal bases in GDPR. These include when it is necessary to satisfy a legal obligation, for contractual performance, for vital interests (e.g. protecting someone), for public interests or when acting under official public authority, for legitimate interests (dependent on purposes, necessity, and balancing against user rights) and the most well-known legal basis, the data subject's consent (and explicit consent in the case of sensitive data) (Art 6, GDPR). We return to the requirements for obtaining consent later. Beyond consent, reasons for processing personal data are clearly varied and leave room for a certain amount of interpretation. When building operators collect personal data, asking for consent (in a publicly accessible building for example), is impractical, and another legal basis for processing personal data might therefore be drawn on. However, whilst all grounds are equal, apart from consent, all other grounds have the requirement of necessity. Given the focus of GDPR on protecting rights of individuals and providing increased control over their personal data, alternative bases to consent will still have to be justified by controllers.

Pseudonymisation and Anonymisation and their risks

Pseudonymous or anonymous data might offer a simpler route in the built environment context, but caution is still needed. The GDPR defines pseudonymisation as the *"processing of personal data in such a manner that the personal data can no longer be attributed to a specific data subject without the use of additional information, provided that such additional information is kept separately and is subject to technical and organisational measures to ensure that the personal data are not attributed to an identified or identifiable natural person"* (Art 4(5), GDPR).

Anonymisation takes this one step further, so that any specific keys to re-identify a person are not retained. Relevant specific techniques are 1) 'data masking' which "*involves stripping out obvious personal identifiers ... to create a data set in which no person identifiers are present*"', 2) 'aggregation', where "... *data is displayed as totals, so no data relating to or identifying any individual is shown.* " and 3) 'derived data items' which use "a set of values that reflect the character of the source data, but which hide the exact original values" [62, pp 51-56].

Whilst the value of anonymisation is appreciated as a privacy enhancing approach, its practical implementation and limitations (when done incorrectly) lead to scepticism of its value [63]. More critically, Ohm argues that the assumption within privacy governance that anonymisation techniques are robust is misguided [64, p. 1704]. He argues the 'release and forget model' where identifiers are suppressed or generalised and aggregated, is flawed, as those can cheaply and easy be re-identified [64, pp. 11-17]. For the EU, the *A29 WP Opinion 05/2014 on Anonymisation Techniques* states the main risks of deanonymisation include: 1) 'singling out' i.e. 'the possibility to isolate some or all records which identify an individual in the dataset;'; 2) 'linkability' i.e. 'the ability to link, at least, two records concerning the same data subject or a group of data subjects (either in the same database or in two different databases)"; and 3) 'inference' i.e. 'the possibility to deduce, with significant probability, the value of an attribute from the values of a set of other attributes." [65, pp. 11-12].

As an example of the risks, Narayanan and Shmatikov famously de-identified anonymous movie ratings on Netflix through cross reference to public information on the Internet Movie Database (IMDB), uncovering sensitive information like potential political preferences of de-anonymised users [66]. Importantly, the process of anonymising a dataset still involves processing personal data; hence the DP rules still apply until it is anonymised. Reiterating such warnings is useful for the emergent adaptive architecture space, as anonymisation is not an infallible solution.

Adaptive Architecture

Personal data then manifests itself again in actuations in the built environment via technical actuators, for example controlling the lighting, air conditioning, media delivery or spatial configuration. As previously argued by Schnädelbach, a closed interactional feedback loop emerges between people's behaviours and the behaviours of buildings [67], where personal data is the driving material. Beyond this interaction in small to medium sized spatial and temporal scales, data is then also used as part of larger, aggregated data archives across larger spaces (i.e. the smart city) and time scales. In this way, each adaptive architectural unit contributes to big data, where inhabitants of architectural spaces cannot know this journey, and cannot know the potential pitfalls of making decisions based on correlations on data without understanding the causalities [68]. Importantly, adaptive buildings as well as IoT devices have only partial user interfaces or none at all. This leads to great opacity with regards to the data processing that occurs between devices and which occurs in the built environment.

Reviewing this broad background, it has become evident that there has been no concentrated focus on people's behaviours relating to the use of personal data through and within Adaptive Architecture. This matters because this type of technology is already widespread as argued above and it continues to grow in pervasiveness, and the public has become increasingly aware of the risk of personal data misuses in different settings [69]. To design liveable buildings in this broad context architects and user experience designers need to understand what kind of questions to ask, aiming to understand what consequences their designs might have. They need to be able to navigate the emerging and quite complex design space.

Instead of concentrating on technical, interactional or architectural aspects in isolation, the research presented here draws on a series of envisioning workshops that surfaced the interaction between 1) people and how they inhabit buildings, 2) the personal data they produce during inhabitation and the data being used to shape the experience in such buildings, 3) the adaptive ecologies of IoT artefacts and the built environment, and 4) the associated rights of individuals, as personal data relates to them. As we will show, we build on the workshop results to contribute a systematic exposition of the emerging design space for adaptive architecture that draws on personal data, and we situate this in the context of the EU General Data Protection Regulation 2016 (GDPR). This then allows us to present the tensions in the temporal, spatial and inhabitation-related relationships of personal data and adaptive buildings, re-usable for the navigation of the emerging, complex issues by future designers.

3. APPROACH

We draw on future envisioning, a common HCI technique, in a series of workshops involving multidisciplinary sets of stakeholders. In our view of the role of future envisioning we follow Reeves' position set out in reaction to the deterministic interpretations that Weiser's above-mentioned vision has received [70]. In those, also exposed in the introduction, Weiser has frequently been critiqued with regards to how accurate his 'forecast' turned out to be. Here, we don't see future envisioning as forecasting or prediction of the future, but instead as much more of a tool to understand a specific design space. As Reeves shows, future envisioning reflects the present and sometimes the past and the technique has value in raising questions and generating principles that can be tested in future, i.e. we are not positioning them as form of prediction. They are inevitably tied to the context that they were developed in, and they accept uncertainty. Envisioning work has been widely employed and most notably for the context of this paper in work around public places [71] and around smart cities more generally [72].

Broadly speaking, the workshops involved participants designing adaptive architectures, using current, widely available digital building technologies. Technology-wise, they are therefore set mostly in the present. We then asked participants to envision a near future, where there is deep integration between available technologies, the beginning of which exist today, and where entirely new interactions might become possible. As we will describe below, workshop participants did envisioning work variously by creating new adaptive architectures, user experiences that can take place in those and design fictions to explore utopian and dystopian scenarios. We did not present fictions to our workshop participants as is common in a variant of the envisioning approach. Three workshops were held in total, and we briefly describe their format in what follows and the data we collected.

Workshop 1

The aim of the first workshop was to test the format of the workshop and to expose a first set of participants to our selected variety of interaction points with an adaptive building. Examples of these are presented in the table below. Initially, we made around 40 of those available. The workshop session lasted for around 90 minutes and was held as part of our regular lab seminar series. Around 20 people took part, who formed five groups. Participants were a mix of academic staff, researchers and graduate students, all broadly with an HCI background. After familiarisation with these input and output devices, participants designed new adaptive built environments that responded to some form of personal data. They used a subset of the interaction point cards, and drew relationships between those on large sheets of paper. This was followed by each group presenting their design, and a discussion. Participants described the functionality of the designs, the flow of personal data through the designs and they reflected on the stakeholders who would be involved in their use.

Table 1 Example of existing inputs and outputs found in the built environment today as used in all three workshops

				
Pin Code Entry *	Thermostat *	IBeacons *	ID card reader *	Escalator **
* Photographs by the authors ** Photograph by Gordon Joly (Own work) [CC BY-SA 3.0 (https://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons				

Workshop 2

For the second workshop, we specifically invited participants who were interested in personal data and the built environment. There were eight participants overall with a diverse set of backgrounds, ranging from smart campus work, to art, human behaviour research, virtual reality and architecture. There were internal and external participants and the workshop lasted for about six hours.

Table 2 Selected Privacy by Design cards to challenge developed designs. The full set of cards has been produced to support designers in their understanding of personal data in design contexts.

		
Right to Rectification	Right to Restriction	Right against Profiling
		
Giving user Consent	Children and Consent	Special Categories of Data

Based on feedback from the pilot workshop, we modified the format of this workshop to (1) set the design task in a council building where citizens access services of the local authorities, such as registering births, acquiring parking permits, etc. Within this context, participant groups could choose from three building areas: the lobby, circulation areas, and the staff kitchen of this building. And (2), after the initial design stage, which was identical to the pilot workshop (familiarization with the devices and design of a new adaptive environment), we added a second stage in which participants were asked to consider operating their designed building for five years, thinking beyond the interactive moment, and to discuss specific user groups such as children, or the elderly. In addition, we challenged teams with selected issues from the Privacy by Design Cards [73]. These were *Right to Rectification*, the *Right to Restriction*, the *Right against Profiling*, *Giving user Consent, Children and Consent*, and *Special Categories of Data* as shown in table 2.

Three groups formed who finalised three designs. For this workshop we collected all design materials as before, including any notes that participants had made. We also audio recorded discussions and the design presentations, which were then both transcribed for the analysis of emerging themes.

Workshop 3

The final workshop was held as part of an international HCI conference. Participants had specifically chosen this workshop due to their interest in both personal data and the built environment. There were 16 participants, all external to our lab, with multi-disciplinary backgrounds. This was an all-day workshop. In addition to the previously described activities (see workshops 1 and 2), we asked groups to develop utopian and dystopian future fictions for each of the designed adaptive buildings and the enabled services. Four groups developed four designs and seven design fictions. Similar to before, we collected all designs and notes and recorded discussions and presentations. In addition, we analysed the produced design fictions and the way they were discussed by all workshop participants. Across the three workshops, the following sets of materials (see Table 3) were generated by our workshop participants.

Table 3 Overview of materials created and data collected across the three workshops, listing workshop (WS), design and description and data collected and analysed. Included data is marked in the table.

WS	Design	Description	Data
1	Smart Lift	Lift operation adapts to flows of inhabitants and waiting times	• Sketches of adaptive architectures created by WS participants • Notes of the oral descriptions of the designs and WS discussion about the designs • Notes of the discussion about the WS format
	Public Phone	A public communication device, the use of which has been made traceable	
	Panic Room	Use of available technology to create 'standard' panic room	
	Lift of the Future	A personalised user experience using a lift	
	Heating System	Room temperature that accounts for various stakeholder perspectives	
2	Triage Lobby	The lobby was discussed as a space for triage, where only a subset of services would be directly provided, while other services are provided in smaller private space in the lobby and throughout the building.	• Sketches of adaptive architectures created by WS participants • Recordings and transcript notes of design discussions and presentations of the final designs • Photographs taken throughout the
	The Invitation	"The Invitation" considers how a building and its infrastructure could invite people to use services and spaces. [Incl: p.11]	

	Staff kitchen	Focussed on the transient nature of communal staff kitchens, its function to potentially encourage people to interact with each other, and to possibly track health-related aspects of its users.	workshop
3	Personal vs. automated Service	Two sides of a lobby space: the public & private; with a focus on the relationship of personal contacts via people versus automated service delivery. Related design fictions: • Lucy the cat • Hell hath no fury	• Sketches of adaptive architecture created by WS participants and the associated design fictions • Recordings of systems and the fictions being presented • Recordings of WS group reflections about the systems and the fictions • Photographs taken throughout the workshop
	Lobby as interface	The design focussed on the lobby as the interface between public space and the semi-public spaces within the council (i.e. the spaces where a case worker might be located) [Incl: p. 12] Related design fictions: • Susan's day out [Incl: p.13] • No Choice [Incl: p.13]	
	Enhancing the waiting time	The group identified waiting as a crucial experience as well as moving from one station to the next. They aimed to make the waiting time more useful [Incl: 14] Related design fictions: • The Immigration Office [Incl: 14] • The Tragedy of Old McDonald [Incl: 15]	
	A public space odyssey	Considering public and employee paths through this public building	
		Related design fictions: • Unfinished Business	

4. WORKSHOP RESULTS

The role of the first workshop was mainly to test and refine the format. Briefly, the main outcomes can be described as follow: Five groups produced five designs. For example, drawing on the available sets of input and output devices, one group proposed a smart lift infrastructure for an office building. Via IBeacons, the flow of people was predicted in the building producing more efficient circulation, while in the lift, media relevant to people's destinations was played. We collected and reviewed the designs and how participants described those. A short focus group session towards the end of the workshop provided additional feedback about the workshop format. Overall, the format worked principally well and the provided devices were useful for sketching interactivity within buildings. As expected, the ambition of designs was relatively low as the workshop was quite short and work was focussed on interactivity, with no designers or architects participating. Participants asked us to provide more variety and balance in the card packs, allow them to expand beyond the provided devices, and they sought space for more future oriented reflections.

Workshop 2

Participants discussed three designs. One for the council office lobby, one for the circulation spaces and one for the communal staff kitchen of the hypothetical council building framing the exercise. Out of these, we are briefly introducing 'The Invitation', addressing the circulation spaces, as a representative example of what participants developed.

Figure 1 'The Invitation' - Design for adaptive circulation spaces in a council building.

For this design, participants integrated existing building elements and infrastructure to provide adaptive circulation spaces in the council building. Ubiquitous Kinect coverage and Wi-Fi device tracking allows the monitoring of inhabitant locations and behaviours and to assess the physical and mental state of a person (e.g. via tracking location, speed, gait, body posture, facial expression, breathing and heart beat). This information is then used by the building to make suggestions of what to do and where to go next. For example, if an employee is stressed and has some time available, they may receive cues from the building, such as an escalator turning on, to lead them to an area to relax. If the building detects that a person is elderly, the building might offer them additional assistance and when a person is judged to pose a security risk, certain building areas are closed off.

Considering how this system would be used after five years, the group proposed that every citizen would wear a token, which allowed them to release selective personal data if required by the building. The group also raised questions of the upgradability of the building to conform to new data standards as well as the potential change in interactions after long periods of time have elapsed. For example, a citizen might have become physically disabled, which creates new challenges inside the building. Additionally, the group raised the question of data permanence over such long periods and how buildings should deal with long periods of no interaction. The same question applies in the case of a person moving to a different city. Does the new council building access the previous interaction data? Or do citizens build up new data every time they move?

Overall, we found that our format adaptations had been beneficial to the workshop. People could relate to the familiar context of a council office and the device cards made the task relatable to the now. Additional device cards and the freedom to add new devices freed up the task and allowed participants to speculate about the near future. It was also felt that while the format of workshop 1 did allow the development of adaptive buildings and associated interactions, it was still too short to investigate life with such buildings in more details. Beyond this, all three designs discussed by the groups provided for very useful anchors to discuss the relationship of personal data and the built environment, and to discuss impacts of the designed for interactions, as already indicated for 'The Invitation'.

Workshop 3

With the larger group of participants, the workshop allowed for four groups of 3-5 people who produced four designs in total. These designs drew on the same task as that used during workshop two. In addition, we asked groups to develop short design fictions that could take place within the proposed adaptive council office spaces. To this end, we split each team in two so that one half could focus on a utopian story and one half could focus on a dystopian story. Stories were read out to the group, and then commented and discussed. We present two designs and four associated design fictions to illustrate the work generated during Workshop 3.

Design 1 – Lobby as Interface between public and semi-public

This group of three participants developed a design for the council office lobby space. As Figure 2 shows, the design focussed on the lobby as the interface between public space and the semi-public spaces within the council (i.e. the spaces where a case worker might be located). Sensors worn on the person and embedded into the environment detect the physical and emotional needs of citizens, as they inhabit the space. The Building passes on the gathered information to the person meeting the citizen, for example via a bell (for a person who has been detected as being angry) or a light (for a person who has been detected as being happy).

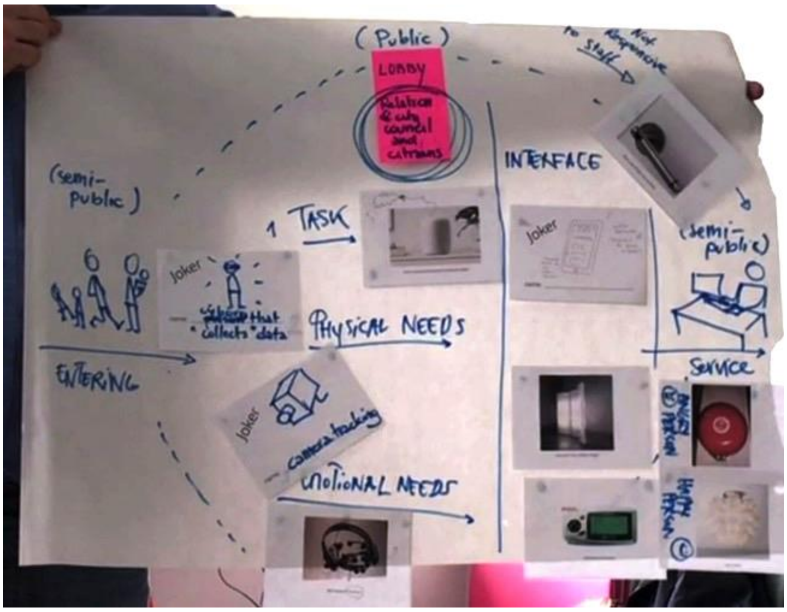

Figure 2 Workshop 3 – Design 1 for a lobby as the key interface between public and semi-public spaces

Within this overall design, the team decided to focus on people rather than on technologies and the presentation focussed on the journey of people through the building. An important distinction made by the team was that the building would be only responsive to visitors, not staff. Hence, there are interfaces that are public facing and others that are only oriented to staff. This design for the lobby then gave rise to two design fictions, which are reproduced below as they were written and read out.

Susan's Day Out – Utopian Fiction

It was a sunny summer day. Susan was late with her council tax payment. She's normally very punctual making payments – but had fallen behind because she was in hospital following a hip-replacement. Susan is 75, is an anxious person and doesn't get on with technology – but she finds encounters with people stressful too. So it's Hobson's choice. Pay online or visit the council offices in person? After some thought she decides on the latter as she might have some explaining to do!

When she gets to the council offices, she finds there are two entrances to the department she needs to visit. One of these doorways indicates that she will be 'sensed'. Information deduced about her emotional and physical needs and forwarded on to help with her request. Going through the second doorway would enable her to access services without being sensed – but she would have to wait much longer to be seen. Her grandson, who is studying computing, tells her stories about hackers and trolls that make her anxious. But she is in a hurry, and wants to avoid the need to queue – just to get it over with quickly. So, she enters the doorway with 'Sensorised Customer Access'. In the confined corridor, she can feel her anxiety escalating – the camera seems like a bloated eye judging her and she hurries to the exit door at the far end. Coming out into a lobby she looks around, and can see people queuing for assistance. But Susan, to her relief, is approached by a member of staff who regards her sympathetically and takes her to a vacant cubical where they both sit down. The clerk says that she realised that Susan's is anxious, and helps Susan to quickly resolve the payment. She tells Susan that the computer notified her of her presence, and of her anxiety, and how she hopes that she is now reassured that everything is ok.

As Susan leaves, she's so relieved and happy that she bypasses the display that tries to attract her attention to ask if she wants the data deleted - she doesn't want to be upset by a further scary interaction. Without a specific instruction, the local authority does the right thing, which in a utopian scenario is to (a) keep the data to help with improvement with services; or (b) takes a default position of deleting the data.

In their discussion of this fiction, workshop participants raised how the technology in this building design supports the services that people provide, in other words making interaction between people more appropriate. A personal service rather than a personalised, automated service. It was also raised that the person mostly went with the sensed route, because it seemed more efficient, disregarding any previous concerns about privacy that she held.

No Choice – Dystopian Fiction

In the newly digitalized world, Sarah has been member of the "My privacy matters" action group, battling the right for being anonymous. Public transportation requires personal data access like position, address and travelling history. Therefore, she was designated to travel by foot. Unfortunately, while crossing a street, a speeding self-driving car did not recognize her as a human subject and drove over her foot, after which she was condemned using a wheelchair. She had to move from her apartment on the third floor to a more adapted room on the first floor. As she did not want to register this change of address through digital city services, she needed to go to city hall in person.

After the great third world war, not many historic buildings had survived in the city, except for the 17th century old castle, up on a mountain peak. Here, the city council decided to install the city hall services as it gave a great view over the city. The city council also found it important that they create a nice and comfortable atmosphere in the city hall, as it is good promotion for the city and its residents. By recognizing wheel chair users, they redesigned adaptive architecture ramps to help less mobile persons into the city hall. However, users have to be video tracked in order for them to be recognized as wheel chair users. They can give their consent by choosing the "YES, YOU CAN PROCESS MY DATA" *entrance. Sarah, however, is still passionate as activist for "My privacy matters", thereby still refusing to reveal her digital identity. So, she takes the "NO, I DON'T WANT TO GIVE CONSENT" entrance, leading her into a separate corridor without video cameras. Here, mostly illegal residents are waiting for their turn. One of them is lying on the ground, singing drinking songs, while occasionally taking a sip of a brown bag. Another one keeps giving her compliments, whistling, coming closer which makes her uncomfortable. In order to motivate herself, she takes a flyer of "My privacy matters" from her bag. Suddenly, a noise starts: BEEP BEEP BEEP!! The door opens.*

Reflecting on this story, participants discussed how being profiled as a certain type of person (a wheel chair user) provides specific access to this building and people might attempt to game such a building by deliberately being profiled in a certain way to gain access. It was raised how choosing to participate in data sharing provides good services and when one chooses not to or one does not have the right personal data to share (e.g. illegal resident), building access is blocked, or a much lower quality route through the building is offered. This goes along with a certain stigmatisation of people who value data privacy, i.e. those who choose building routes that do not demand personal data. It was also discussed how lack of camera supervision in a space brought together marginalised people and 'bad behaviour', as if cameras were needed for people to behave well.

Design 2 – Enhancing the waiting time

The four participants in this group identified waiting as a crucial experience as well as moving from 'service station' to the next, within the larger organisation of the council building. They focussed on the circulation area of the council office. They aimed to make the waiting time more useful. For example, the building could provide more information and that information could be used optimised the journey, for example identifying bottlenecks.

The idea was to track people as they move around the building and this would include everyone who comes into the building. This could be done through implicit or explicit tracking. The former might for example use IBeacons or cameras, while this was judged to be intrusive. Alternatively, the latter might involved the use of waiting numbers (dispensed somewhere in the space) as a tracker. Applications could be built on top of this kind of tracking infrastructure. One example would be a congestion map (many people are applying for a marriage licence today, and it would not be a good idea to go to this division today). It could also indicate how long the wait might be so that someone can decide to start some work for example. Beyond this real-time use, participants presented how this could be use for-offline analysis and space / service optimisation. As before, this design gave rise to two design fictions, which are included below.

The Immigration Office – Utopian Vision

This is a true story. The place: Japan. The year: 2020. - Oh no! Time to renew my Japanese residence card! I don't want to even think about it. Last year, I did it at the small ward office in Honmoku. It was horrible. It was raining and cold. It took the whole day as I was shuttled between different cramped offices without ever encountering anyone who spoke English. By the end of the day, I was amazed that they actually gave me a new card - I had no idea what had happened.

I lost one day of work and 3 litres of my body weight in sweat because I was so anxious. A few months ago I moved to a bigger city. My colleague told me about the new system that is being implemented in Shinjuku ward. It's supposed to make everything much easier using neural networks or something. I cannot really believe it. Today is my appointment. I already sent my preliminary application. They gave an appointment slot that is supposed to be optimal for me by looking at my calendar. It even includes the projected total waiting time - 93 minutes. I doubt it!

When I walk to the subway station, it starts raining, but not as bad as the last time. Is this a good or bad sign? As I arrive at the ward office, I am met by a nice gleaming machine. As I approach it automatically switches to English. Amazing! Maybe this will work! The machine even seems to know why I am here! It says "Residence Card" and a small round token pops out. I pick it up. It feels nice, almost like a small warm stone. On the token is a number - this is the first desk I am going to. There is a small map to help me find the way, and even a blue blip showing where I am right now. There is also an estimated waiting time - 4 minutes and 34 seconds. Exactly the time it will take me to walk over there!

I arrive at the desk just as the previous customer is leaving, and hand over my documents, including the old residence card. The clerk takes them, makes a quick check, and nods. My token changes. This time it shows another location and a much longer waiting time: 68 minutes. I turn it over. On the back are some useful Japanese words that I would be able to learn in this time! I start learning first Japanese kanji sign. "Niji" – rainbow. It is pretty complicated. But soon I notice something else: The token has detected one of my colleagues who is also waiting. I walk over to a lounge area in the other end of the building. Was this by accident or did the system actually match us up? In any case we have a nice chat and before I know it the token buzzes. It shows a time of 3 minutes and 12 seconds, exactly the time it takes to get to the next counter.

I arrive at the next desk. The clerk actually seems to know a little bit of English! "Welcome" he says. He asks me a few simple questions, and it all seems to check out. Before I know it, the clerk gives me my new residence card. Two more years approved! AWESOME! "I wouldn't mind coming back in a month instead of two years", I joke. I'm not sure if the clerk understands. As I leave, I am asked to drop off my token. There are two choices. Either I can be completely anonymous and have all my data wiped. I see someone putting their token there - it gives off a weird sound, like it was shredding paper! The other option is to give away all my data forever to everyone to contribute to make my experience even more AWESOME the next time. Of course, I choose this option, safe in the knowledge that nothing bad can ever happen to anything that's stored on a computer server. Exactly 93 minutes after I arrived I walk out. The rain has stopped and the sun is shining! I use my new Japanese word: Niji ga arimasu - there is a rainbow!

The workshop group reflected that the consequences of sharing the data (from the token) are really quite unknowable and it was discussed how they could be made understandable (building terms and conditions?). People commented on how manipulative the system was, as it both got the waiting citizen to learn new language skills and got them together with an acquaintance. In neither case was the person asked for input on these. It was noted how the office building seemed to be entirely conventional, with the design focussing on more efficient use of the building. Participants discussed how the building could have highlighted the best routes to take and how building adaptivity might occur over longer periods of time. Finally, the ability of the design to switch to English was raised, and whether this would amount to 'detecting foreigners', embedding a questionable social attitude into the built environment.

The Tragedy of Old McDonald – Dystopian Vision

MacDonald, 156 years old and 62% bionically enhanced, is going to work in 2070 as he has been doing for 80 years. Only another 10 before he can think about retirement. He woke up with an uneasy feeling today. His breakfast didn't taste right. He wasn't informed of any changes to his nutritional diet for optimised personalised extended living. He'll have to contact his service provider immediately. He decides to go to the local council. On the way, his arm starts itching and his throat swelling. He is getting worried and expecting that his token may be mal-functioning. Getting out of the self-driving taxi, the fare displayed is £2000. The system thinks he is a coal token holder. Last time he checked he had been upgraded to pearl. That sets him back about 80 years.

He has no option but to run for it, as he can't pay the fare, knowing that he'd be reported to the police. He's never heard of the token having malfunctioned in the past. His retina screen implant starts flashing a warning: 'Arm hardware not recognised. Please update certificate.' He walks into the council and gets told that he needs to come back in two weeks because he is only a coal token holder. His leg starts to mal-function. He hobbles over to the waiting room to try and plead his case. An alarm goes off and the warning system informs users there that there is a threat in the building due to an unidentified suspect with an invalid token. Now he is really worried. Invalid token holders can be shot on sight in council buildings. His implant malfunctions, having rendered him immobilised. He is a sitting, shivering duck.

Discussing this story, participants reflected on the universal, integrated data system governing the entire person's life, including the way they were billed, how their body functions and what access to services they get. No failsafe mechanisms were provided and no graceful degradation when data error might occur. Another point of discussion was the role of the token and its possible role in adaptive built environments. In that society, the token was essential for existence. But, does the token contain all the data or is data stored somewhere in the cloud.

Cross-workshop analysis of common themes

As part of our future-envisioning approach we carefully analysed data emerging from each of the workshops along the way. Workshop one mainly confirmed our direction and supported the development of the workshop format, while some common themes started emerging already. Workshops two and three then delivered rich data to draw on as outlined above. We reviewed all records of the produced designs and their discussions during presentations. Beyond the designs, the final workshop included a discussion conducted with our participants to record common themes developing from each of the design fictions. Developing this further involved a clustering exercise conducted by the authors post-workshop that started collapsing what was discussed into a manageable number. In concluding the presentation of the workshop data, we briefly outline the recurring themes in the table below, and these form the basis for our discussion presented in the following section.

Table 4 Twelve recurring themes emerging across the three workshops

Data and Building Adaptivity

The spectrum of proposed building adaptivity ranged from re-using existing infrastructure (e.g. making circulation infrastructure to people) to implementing entirely new building functionality (e.g. shape-shifting floor adapting to particular exchange between member of the public and staff).

Personal Data – Shared Space

Participants discussed the tension between personal data being private and mapping this data to shared spaces inside buildings, especially when this data might reveal sensitive data.

Consent for data use in public space – Building Terms and Conditions

How might people provide consent for a public use of their personal data and do they have to provide consent? This also has implications regarding the reaffirming of consent over time as devices and policies update. What would it mean to have to

Buildings sensing – Inhabitants providing personal data - Tokens

Buildings sense (via their technical infrastructure) certain data about their inhabitants and might record specific kinds of personal data as people journey through them. In addition, inhabitants might use their own devices to provide personal data accept a building's terms and conditions before entering and using it, and how might explicit consent be requested and delivered?

augmenting what the building senses. Privacy tokens that would allow participants to control the release of only the minimum amount of personal data were discussed.

Personal data - Profiling

Participants discussed how building adaptivity can be in response to profiled inhabitants rather than identified inhabitants, preserving privacy by design.

Stakeholders – Variations in Adaptivity

How do different stakeholders, such as the public and employees, make use of building adaptivity differently? Compared to members of the public, employees have access to other parts of the building and other parts of the technical infrastructure and a circulation system for example would guide them differently.

Permanence of buildings – Permanence of data

Participants discussed the relative permanence of buildings, computing infrastructure, data and data storage solutions. There are long-term interactions with a building, such as repeated uses of the same building or interactions with buildings of the same type but in different neighbourhoods or cities. During such times, the interaction might change because of personal circumstances, such as moving to a different city or becoming physically impaired.

Locus of control and interaction

Workshop participants discussed how inhabitants would identify locations for control and interaction. With ubiquitous Kinect coverage and recognition, there would be interaction with the building 'everywhere and always'. Much more legible are specific interaction points for example at a service counter, for example using voice recognition.

Data provision tied to use of buildings

There seems to be an increasing dependency between using places and the handover of personal data. When such data is not given, certain places become inaccessible to those people who have no data, whose technology is broken or who value privacy.

Personal service versus personalised service

There was a distinct difference in emphasis between using personal data to provide better access to people within the exemplar council offices (a highly personal service) in comparison to using personal data to provide better quality automation (a personalised service).

In the moment interactivity – long term adaptivity

Many groups designed for in the moment interactivity, where personal data was used to adapt and tailor the next momentary interaction. This clearly goes alongside of, and sometimes stands in contrast to, concerns of longer-term adaptivity, where the data is required for longer, where the analysis is different and where the purpose of the uses of data is different.

Building rights and responsibilities – Personal data rights and responsibilities

There was recurring discussion of the differences in the rights and responsibilities that come with operating and occupying a building versus those that come with the storage and access to and of personal data (wherever that might be stored). This is particularly important as those that operate buildings increasingly overlap with those who control data.

5. THE RELATIONSHIP BETWEEN PEOPLE'S BEHAVIOUR, PERSONAL DATA AND ADAPTIVE BUILDINGS

For the discussion, we draw on the analysis of the adaptive buildings designed by workshop participants, the description of the user experiences that are enabled within these buildings, the design fictions, and our initial analysis of the common themes raised throughout the workshops. Our aim was to present the emerging design space in a way that would allow its navigation by future architects and user experience designers, both for analysis and for design. Inspecting the themes presented above lead us to discuss the design space through three overarching categories: 1) the temporal relationships of people's behaviour, personal data and adaptive architecture 2) the spatial relationships of people's behaviour, personal data and adaptive architecture and 3) the impact of personal data use on the ways we inhabit adaptive architecture.

We have chosen to put this into context of the European General Data Protection Regulation (GDPR) because the work was conducted in Europe and it is now being framed by it. In this way, the GDPR can be used to formulate requirements for the emergence of compliant adaptive architecture applications, e.g. they are built according to legal principles of accountability, transparency, and privacy by design, and so forth. Considering this will allow designers to create liveable adaptive buildings that are fit for purpose and ultimately acceptable to its inhabitants. Avoiding engagement with law in an anticipatory, proactive way might force adaptive architecture into being regulated in a reactionary, restrictive way, to make it compliant in the future. We are, therefore, presenting our work as projective, rather than 'only' reflective of the work conducted by workshop participants.

Design space and design tensions

As the previously presented themes demonstrate, there are multiple issues to be considered when designing for this three-way relationship of people's behaviour, personal data, and the adaptive building. Some of the demands seem to stand in direct opposition, whereas others are presentable as continuum of key issues in this design space. Thus, we have opted for design tensions as the basic form of our design space presentation, which avoids setting boundaries or simplifying the problem [74, p. 413]. In particular, design tensions *"… conceptualize design not as problem solving, but as goal balancing. They draw explicit attention to conflicts in system design that cannot be solved, but only handled via compromise"*[74]. One previously reported on and very succinct form of presenting such design tensions is tension space analysis [22]. Tension space analysis proposes a systematic way of representing any emerging design tensions in graphical radar charts. This form of presentation ensures that results remain relevant across a variety of future designs, as the described tensions need to be considered but they cannot necessarily be resolved or comprehensively addressed. For example, it is difficult to design both for in the moment adaptivity *and* long-term building interactions, as it is hard to cater both for the responsibilities that buildings come with and the responsibilities that are associated with personal data. Instead of definitively prioritising one over the other, both ends of a given spectrum of themes is recorded and used throughout the analysis and design process.

To illustrate the use of the radar chart diagrams from a designer's perspective, we use an example of a fictional building (based on workshop results) for each of the issues we identified: temporal (Fig. 3), spatial (Fig. 4), inhabitation (Fig. 5). We will return to these to discuss future uses of the uncovered design tensions for analysis and design.

Temporal aspects

Tensions in life times of buildings and data

Neither buildings nor data are fundamentally permanent. Some survive a very long time (e.g., the Pyramids, Egyptian writing). Most disappear much more quickly than this. In both cases, societies make distinct choices about which buildings (e.g. the listing of buildings) and which data (e.g., data protection legislation) to maintain under which circumstances.

Building as well as demolition is energy intensive, and accordingly, there are clear advantages to increasing the life span of buildings. Surprisingly, newly designed buildings have a seemingly low expected life span of around 60 to 120 years. However, different parts of buildings are adaptable to different extents, and careful adaptations can substantially increase the usefulness and, therefore, life span of buildings [75]. Importantly, the reasons for demolishing buildings bear little relation to the physical state of the structure [76]. For example, Liu et all argue how external factors have been the driving force in the rapid re-structuring of Chinese cities (rather than factors relating to the buildings themselves) [77]. To add to the uncertainty about designed versus actual life spans of buildings, it can be observed how some 'temporary' structures survive a very long time and some acclaimed architecture faces the wrecking ball rather early [78]. Beanland also points out how tight budgets today further constrain the life spans of today's buildings.

Similar to buildings, personal data can also have an expected lifetime. Publicly funded research projects across OECD countries are expected to make collected research data openly available, where the RCUK guidance offers one principled approach [79]. Depending on the type of data, this includes the recommendation of 'indefinite' retention of some collected data, and general guidance to retain data for at least ten years following the publication of research. This requires a judgement about the perceived long-term value of data. Legal, ethical, or commercial constraints on the release of research data are important considerations in this process. This will apply less directly to most buildings beyond the research context. What does apply to general as well as adaptive buildings is the EU's General Data Protection Regulation (GDPR), having come into force in May 2018. It defines the framework for handling personal data, stipulating it shall be *'… kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the personal data are processed;'* [62, Principles – Article 5 GDPR]. GDPR only applies to data relating to an identified or identifiable individual, i.e., personal data. This includes pseudonymised data when it is reasonably likely that additional information could be used to directly or indirectly single out an individual (Recital 26, GDPR). Truly anonymous data (where there is no link back to the data subject) is no longer subject to the GDPR and can be used in less prescriptive ways, without time limits (Recital 26, GDPR).

Considering the above, it is evident that situations will arise in Adaptive Buildings where the expected life times of the built environment and the associated data will diverge. Designers will need to look at what to ultimately do with the personal data, where the relevant building adaptivity has been taken away and with adaptive building components where the data to operate them has been deleted.

Tensions between organisations and the rights of individuals

To operate buildings efficiently and sustainably, organisations have an interest to have long-term access to data that could help with those aims. For example, at least a year's worth of behavioural data is needed to enable analysis of building usage across all seasons. Organisations might also expect to retain access to information about individuals, for example to tailor the user experience in an adaptive single office to the occupying individual worker. Beyond this, some organisations might desire access to such personal data for surveillance purposes, for example to measure work patterns and work efficiency. Controversially, Amazon at their newest warehouse are integrating data from workstations and general building surveillance to monitor the behaviour of their workers [80].

This contrasts with interests of the individual, which are represented through a spectrum of control rights found in Articles 15-20 GDPR. Firstly, there is a right to access personal data (Art 15), where subjects can find out what data a controller holds. This is coupled with a right to rectification (Art 16), where they can correct any errors therein. They also have a right to object to processing (Art 21) or to even restrict it (Art 18), where a data controller will have to limit or even stop processing. Then, there is a right to data portability (Article 20), where a subject receives all their data in a commonly used, machine readable, structured, interoperable format to transmit to another controller. Lastly, there is a right to erasure/to be forgotten (Art 17), where all data can be removed and deleted at the subject's request.

In reality, the tensions between some of the data processing wishes of data organisations and the rights of the individual will lead to very complex situations, for example when some individuals have exercised their rights over some aspects of the data but others have not, and organisations are forced to keep track of this. In this context, Urquhart et al track the challenges that emerge when the right to data portability is exercised in an IoT context, also applicable to adaptive buildings [81].

In-the-moment adaptivity versus long-term interactions

Directly related to the above, the temporal relationships sketched out matter for designed architectural adaptivity. Many adaptive architecture designs focus on 'in-the-moment' interactivity and adaptivity whilst also being created for use by individuals or at least small groups of people. We also saw such focus during the workshop sessions. For responsive adaptivity in tightly knit feedback loops between person and adaptive environment, high fidelity of personal data at low latency is required. For example, to make an environment follow the respiration of an inhabitant as in the ExoBuilding prototype [43], such data would be required, and the identification of natural persons in such data is ultimately possible.

Longer-term architectural adaptivity arguably has different data requirements. Storing high fidelity data for every individual will become impractical quickly and difficult to reconcile with the requirements of the GDPR. Also, long-term uses of data in a building context will require data analysis and aggregation at a higher level. For example, the already somewhat slower reaction of Khan's Open Columns was achieved by drawing on by definition aggregated personal data, measuring $C0_2$ levels in the room [41]. For an organisation to successfully manage adaptivity in their building, an even more abstracted view of personal data is required, considering weeks, months and years of data archives.

To enable both in-the-moment adaptivity and the long-term uses of personal data (to tailor adaptivity over time), a complex and on-going relationship between current and past building inhabitants and the organisations that look after buildings emerges.

Temporal Design Tensions

The figure below illustrates the design tensions that are related to the temporal aspects of the emerging design space. The diagram tracks the following three design tensions:

1. The lifetime of buildings and how this might relate to the lifetime of data associated with adaptivity in that building,
2. The rights of individuals with regards to data (and data access) versus the needs of organisations in that regard, and

3. To what extent in-the-moment adaptivity is enabled in a building and sets this in relation to the extent of which long-term interactions are possible.

These are marked out in the radar charts as three pairs of opposing issues that are difficult to reconcile with each other. To illustrate the use of the diagram below together with those presented in Figures 4 and 5 further down, we populate them with the example of a fictional adaptive building and its properties. We are proposing that designers will use all three diagrams next to each other to document the tensions and continua that exist when designing adaptive buildings that draw on people's behaviour via personal data.

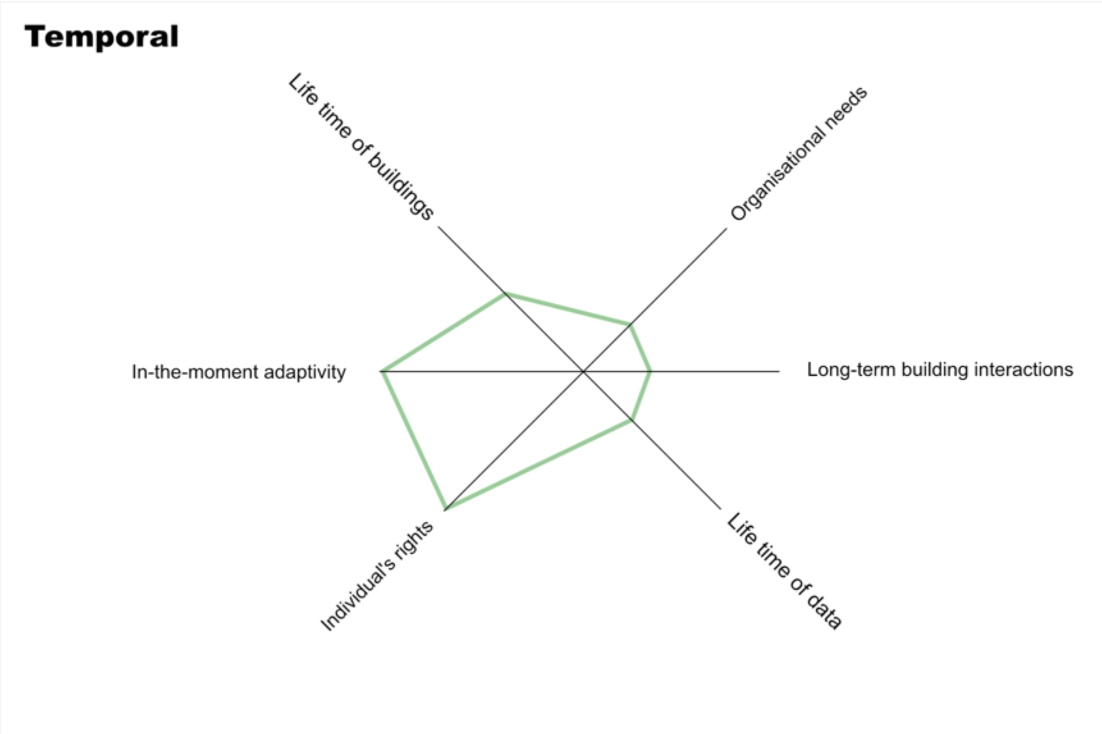

Figure 3 Temporal Design Tensions.

For this illustration purpose we draw on the council office building context, which guided the envisioning workshop design process. To best illustrate the use of the diagrams, we combine ideas from multiple designs proposed by workshop participants. This results in the following functionality in a fictional adaptive council building (shown as green 'footprint' in the tension space diagrams):

1. The building is capable of adapting its physical layout to manage the flow of people through the building (e.g. by opening and closing routes),
2. It tailors service delivery for each visitor (e.g. drawing on personal data recorded 'now'), and
3. It provides specifically tailored spaces (e.g. for a person to relax in).

The temporal tensions identified, could, for example, prompt the following speculative design for how data and building are related. The building systems observe all rights of the individual with regards to their individual personal data. It requires the provision of a person's consent as the legal basis for processing personal data for in-the-moment-adaptivity only. This in turn restrains the organisation from storing data long-term unless it is anonymised. It also restrains the lifetime of building adaptivity relevant personal data to a short time frame, while the building has a standard lifetime (shown in the middle of the building life time graph). As consent is provided, personal data can be used to enable full in-the-moment adaptivity (e.g. adapting routes, service delivery, and the relaxation room). But it offers only limited long-term interaction if personal data is not being retained. Long-term use would need to be specified in the consent agreement at moment of collection.

Spatial aspects of uses of data

Adaptive artefacts, rooms, buildings and cities

Much work in adaptive environments research has focused on single artefacts and rooms. This has allowed for relatively more unusual features in buildings to be experimented with, often manifested in individual prototypes. As mentioned in the introduction, there are, for example, rooms that follow a person's physiological or psychological behaviour and facades that respond to social media feeds. In this context, personal data is being used to drive an individual prototype, for example a lift that automatically plays a person's preferred music, or the soundscape of a room that is driven by real-time breathing data [82]. Arguably, the data collection, use, and the data controller can be made more legible in these circumstances.

As highlighted in the introduction, adaptive environments comprise an ecology of adaptive artefacts, rooms, and buildings that become integrated in the adaptive city. Multiple designs by workshop participants surfaced the opportunities that arise when existing adaptive building elements such as automatic doors, lifts and escalators, adaptive lighting, ventilation systems and so on become better integrated through the use of personal data. Furthermore, there was speculation about how this would be integrated across multiple buildings and then urban environments. For this to work, technical infrastructure is required that makes sharing of such data possible, with regards to interchangeable data formats and standards, as for example discussed by Milenkovic [83]. In addition, there will have to be detailed consideration of the different use of collected personal data. This is especially important when uses differ from those for which data was collected. Who controls the data at each stage and the various rights that the GDPR provides to individuals need to be considered.

Where does data live – relationship of buildings and data

Despite the non-permanence of buildings *and* data, data tends to be archived within buildings. Data can live on mobile devices (mobiles, cars, IoT), but this tends to be backed up to the cloud, which is again stored in data centres in buildings. For the purposes of this paper, we are excluding data that is exclusively stored on mobile devices from our consideration. However, we realise that the boundary is rather grey, as there seem to be no current storage mechanisms of digital data that are actually tied to physical location. Physical records of personal data such as birth records are traditionally stored in archives and libraries, for example, and therefore in the buildings that are used to access that data. Digital records of personal data are stored on physical storage media within buildings. Some of these are accessed in the building that holds the data (e.g. via physical access to a computer containing data). Increasingly, data and copies of data are stored in the cloud. Then, the building in which data is stored is different from the building in which it is used.

For buildings to become adaptive to personal data, some of that data might be stored in the same building (e.g. the high fidelity, real-time data) while backups of that data and any longer-term analysis might be stored off-site. The two data sources (local and remote) would then be combined, for example to inform momentary interactions with longer-term profile data.

There is, therefore, tension between the demands of storing data safely locally (Where does the backup live?) and storing data in the cloud (How can information privacy and user control be maintained?). From a GDPR perspective, where personal data lives is critical. The legality of data being sent outside the EU depends on the adequacy of destination third country data protection regimes (Chapter V, GDPR). Various mechanisms are used to govern legality of transfers, from binding contract clauses and European Commission adequacy decisions to a bilateral EU-US agreement for US service providers [84]. However, the opacity surrounding cloud storage (particularly for notifying users where their data is stored) means adequate protection and control over data can frustrate end-user information privacy rights [85]. Using this as a prompt, adaptive architecture could find new opportunities for local data storage approaches to avoid legal challenges of cloud storage e.g. storage that is built into the fabric of buildings while leaving it accessible for it to be maintained.

Provided by people versus sensed in the environment

Broadly speaking, participants discussed two ways for personal data to be generated during the workshops. People provide data about themselves. This would include data that people give when asked (e.g., their name, ID, documents) or provide via electronic means (e.g. send a file, fill in an online form), or provide via devices they carry (e.g. tokens, cards, mobile devices, fitness trackers), and that personal data which is generated through the use of social media, when this can be tied to a place. As the examples above show, such provided data does not necessarily require the use of sensors, but those might be used when built into personal devices. Importantly, the source of such personal data is the person themselves, which in principle offers greater opportunities for controlling the flow of such data.

In contrast to the above, but often working in parallel to it, personal data can also be sensed by the building infrastructure via sensors being embedded into the environment. This would for example include CCTV for face recognition, Automatic Number Plate recognition, voice recognition, and, for example, extensive Kinect coverage as proposed within the workshop design “The Invitation”, described above. Conceptually, sensors built into the environment constitute a case of personal data being ‘taken’ in some sense, and building occupants can be unaware that their data is collected and being used. Their levels of control over the flow of personal data generated in this way is already diminished, and workshop participants proposed for example personal tokens that would regulate how their personal data would be used in such environments.

This can be put in the context of GDPR Article 25, which mandates data protection by design and default. Appropriate technical and organisational measures should be taken by data controllers to protect personal data processing. Responsibilities can lie at different points in the data supply chain [86] but in responding to these, there are a range of technical measures that can be taken [87].

Privacy enhancing technologies (PETs) are one approach, putting in place technical measures for identity and access management, obfuscation techniques to mask identity [88], or minimizing data collection in the first place. Privacy engineering [89] and usable privacy & security seek technical solutions to privacy challenges, such as creating privacy preserving analytics or machine-readable privacy preferences in browsers [90]. Distributed analytics [91], differential privacy in databases, and personal information management systems [92] are just a few examples.

How these can be integrated into adaptive architecture supply chains is an interesting question, as many of these have emerged for web-based environments. The privacy and security practices around emergent IoT devices, upon which adaptive architecture will rely, are emergent, and accordingly piecemeal and inadequate [93].

Spatial Design Tensions

The figure below highlights the three design tensions that are related to the spatial aspects of the design space. The diagrams tracks:

1. The continuum from adaptive artefacts, via adaptive rooms to buildings and to the adaptive city.

2. The extent to which the provision of personal data is through the individual and sensors they own in contrast to sensing being embedded into the environment.
3. The relationship of data storage and buildings, from data being stored off-site to data being stored in the building from which it is accessed.

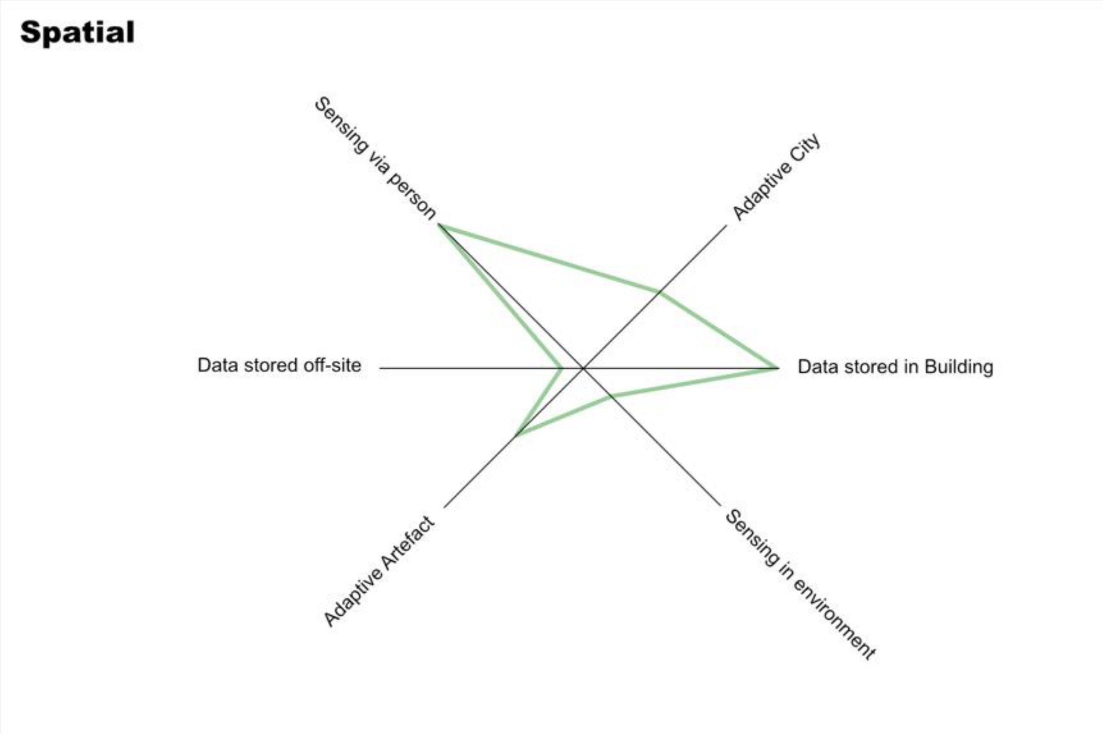

Figure 4 Spatial Design Tensions

Continuing the graphical representations of the speculative adaptive council offices, we show the footprint of this building through the green outline in Figure 4. As it is envisioned here, the example focuses on the scale of rooms and buildings and therefore does not consider the adaptivity of artefacts or that of the city as a whole. The council has decided that only dedicated data storage inside this adaptive building can ensure full compliance with the GDPR and they invested in a dedicated data storage facility on site. Only anonymised data is stored in the cloud, specifically to enable longer-term interactions. Personal data is nearly exclusively provided by individuals themselves, via the aforementioned routes. The council has implemented a simple way to provide consent to use sensors built into the environment, for example via a dedicated mobile application or a token that can be borrowed for the time of the visit.

Uses of data related to Inhabitation

Adaptivity to single person versus multiple people in shared space

Particularly, when adaptive artefacts, building features and rooms remain separate from each other, it is conceivable how only a single person might inhabit them. Their personal data is then the driver for the adaptive features around them and they alone are impacted by the emerging feedback loop between their behaviour and that of the environment. This seems most appropriate for the processing of 'special categories of personal data' (defined by the GDPR in the introduction), as there is a mechanism to maintain privacy by providing spatial privacy. Most buildings are inhabited by more than one person, though, and even for separate adaptive features, multiple people will be using those over time, requiring links to be made between the personal data from a number of individuals to the single adaptive feature or room.

Above, we have already introduced the ways in which individual adaptive artefacts, features, and rooms become integrated into larger adaptive ecologies. When this occurs, the behaviour of multiple people drives the behaviour of multiple adaptive features, which might be integrated in the same spatial context. In turn, the effects of such architectural behaviours are upon multiple individuals sharing the same adaptive environment. The use of the GDPR 'special categories of personal data' seems inappropriate for this use in shared places, and a strategy might be to draw on anonymous data or use other strategies to mask the source of specific environmental adaptivity.

While, there is legal precedent for reasonable expectations to privacy in public space [94], it is an on-going concern how privacy is managed in shared social spaces. Data Protection law focuses on rights of individuals, and does not adequately accommodate rights of collectives or groups [95]. Additionally, legal concepts of privacy often focus on abstract rights to be let alone, to secrecy, or confidentiality. However, privacy is contextual. Nissenbaum's framing of privacy is useful here, i.e. privacy is preserving the contextual integrity of information flows. Harm occurs when information leaves this context. It can be amenable to the situated practices around technologies in different deployment settings [96]. To build on this, privacy scholarship needs a greater understanding of how privacy is managed in context. CSCW and HCI provide some studies in this regard [97], showing the importance of controlling who can access information, particularly within domestic hierarchies (e.g. children not wanting parents to see information, but not being as concerned about companies seeing it). The co-constructed nature of personal data in homes, so called 'interpersonal data', is also problematic because individual members of a space can struggle to assert their rights over such data [98]. These are established problems adaptive architecture applications need to address.

Provision of personal data and building use

When personal data is gathered by technical infrastructure set into the built environment, the collection of personal data about every person entering the space can become the norm. Automatic number plate recognition on the motorways is a good example, where driving on the motorway means implicitly agreeing to that personal data being collected. The only option to not participate in this seems to be to not use the motorways and count on the fact that other parts of the road system are not similarly covered. In those circumstances where personal data is collected by default, data controllers can clearly not rely on people having provided consent. According to Article 4(10) GDPR, consent is any '*freely given, specific, informed, unambiguous indication of the data subject's wishes*', which can be through an active statement or other form of affirmative action (written, oral or electronic). This means if a user does nothing, is silent, or a controller relies on a pre-ticked box, this does not amount to consent (Recital 32, GDPR). Accordingly, consent needs to be an action. Passive behaviour is insufficient.

Consent needs to be for specific, documented purposes; it has to be provable, demonstrable, and capable of withdrawal (Art 6; Recital 32 GDPR). The bar is even higher if adaptive buildings use biometric or health data, as data controllers need explicit consent from data subjects, while what explicit consent really means is ill-defined in the GDPR.

Workshop participants brought the tension between providing access to personal data and access to buildings as a whole but also adaptive features within buildings to the fore. Those people who do not have functioning technical access to their own personal data, whose stored personal data has been corrupted, or who do not agree to participate can then be faced with the choice not to enter a particular place. Or they might be offered an alternative route, which does not require the provision of personal data. This route might be of lower service quality in some way.

As the nature of consent giving is not tightly prescribed in law, it opens up possibilities for designers, as regulators, to design different mechanisms and actions into the technology to signify consent. One approach is to use two-stage verification by double-checking with a subject via two mediums, e.g., email and text (Article 29 Working Party, 2017). Although other lawful processing grounds mechanisms may be used when necessary, there are interesting opportunities for designing ambient consent notifications for adaptive architecture.

Building and data responsibilities

As the operator of a building or public place whether it is private or public facing, one has several responsibilities. For example, the duties of private landlords in England and Wales include providing a safe and health hazard free environment, providing information about energy performance, and checking whether a tenant has the right to rent a property [99]. In public buildings, these additionally include providing access to the public in a safe and accessible way, providing access to minors (e.g. in school environments), providing access to people with reduced mental as well as physical abilities [100]. Furthermore, building owners will aim to make buildings comfortable to a variety of inhabitants while keeping it resource efficient.

Increasingly, with sensors and actuators becoming more commonplace in the built environment, building operators are also becoming data controllers. They are, therefore, faced with a second set of sometimes-conflicting responsibilities. Broadly speaking, the responsibilities of the data controller include the establishment of the legal basis for the data processing. This includes determining both the purposes of collection and how personal data is processed (Art 4(1) GDPR), while keeping the data safe from un-authorised access. It also involves enabling the user's rights with regards to their own personal data enshrined in the GDPR, destroying data when requested, and not collecting data about children without the consent of their parent/legal guardian when it relates to use of particular services (such as social media or online shopping). Finally, building operators/data controllers need to provide organisational and technical safeguards when handling data on their behalf (Art 28 GDPR).

Without surfacing the relationship between data controllers and users through interactions with the building, establishing who the data controller is can be a big challenge. An occupant may have relations with building managers, letting agencies, IoT device service providers, and landlords to name a few. The data supply chain in a building may involve numerous actors, each with different responsibilities. An organisation that runs a digital building management system observing exit/entry, temperature or lighting, may be more clearly a data controller. However, a building controller focused on more analogue information may still become a data controller, if they hold sufficient non-personal data that on aggregate singles out individuals. A number of issues clearly arise. When a minor accesses a building on their own, the building might not be able to offer some of its adaptive features, as the use of personal data is restricted in this circumstance. If a building provided adaptivity on release of personal data in a shared space, non-authorised access to personal data would clearly be given to those sharing the space. The emergence of a more trustworthy adaptive architecture future requires greater transparency and accountability around how personal data is used. The processing needs to be compliant and accounts of how this is being done need to be provided to end users (Article 5(2) GDPR). Accountability is difficult because user data handling by ambient technologies is opaque, impacting scope for control of data use; the lack or partial user interface challenging consent mechanisms; the unseen machine-to-machine communications complicate access oversight; and dominant cloud storage approaches create jurisdiction challenges to be overcome [101].

Design Tensions related to Inhabitation

The figure below illustrates the design tensions that are related to how people inhabit adaptive buildings. The diagram tracks:

1. The tension that arises through individuals and multiple people using private and shared spaces.
2. The extent to which building use and provision of personal data are dependent on each other.
3. The tension between building operator and data controller responsibilities.

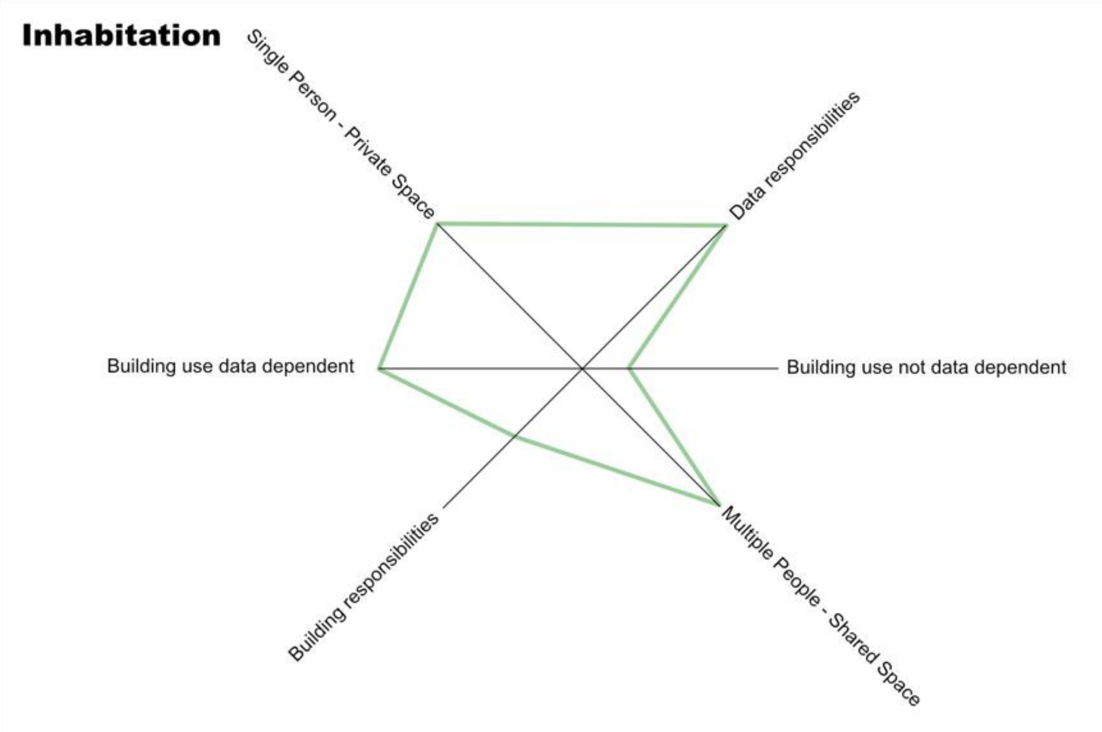

Figure 5 Inhabitation-related Design Tensions

We continue illustration of the use of the tension space in this context by drawing on the speculative, adaptive council buildings (compare Figures 3 and 4). The building is capable of adapting to single inhabitants in private spaces (e.g. the relaxation room, where personal data will be exposed) and to multiple people in shared spaces (e.g. for the adaptive circulation routes, where personal data is not being shown). Many of the adaptive features in the building are dependent on people providing personal data to the building and will not work without that data. When such data is not available for whatever reason, the council falls back on providing a personalised service, as highlighted during the workshops. As access to adaptive features in the building is data provision dependent, access to the building is selective. This can only be overcome with additional personalised services (i.e., by people providing the service).

Future uses of tension space surrounding Adaptive Architecture and personal data

To illustrate the three sets of tensions, across temporal, spatial and inhabitation-related issues, we drew on a fictional building that reflected what participants had designed during our workshops. We propose that the presented tension space will be useable for the analysis of existing adaptive buildings and for the co-design of future adaptive buildings. Such work would make use of the three unfilled radar charts and it would draw on the textual description of the tensions.

For existing buildings that use personal data in their operations [102], inhabitants and operators work together to map where a given building sits in relation to the tensions presented in this paper. This will allow inhabitants to better understand the paths of personal data through their building in the context of the varied uses of that building. It will also support them with the information required to shape future operation strategies but also re-designs for that existing building.

For new designs, the proposed tension space will be useful for the early phases of a project, setting out the broad strategies for adaptivity, data flows and operations. All three radar charts would be used alongside each other and relevant stakeholders would discuss the proposed building with regards to what kind of footprint it creates across the three charts. Using the technique iteratively then will also allow stakeholders to consider variations. For example, radar charts can be populated for concurrently available parts of a building. There might be the short-term use of sensitive data for in-the-moment adaptivity in one part of the building, while archival collection of anonymised personal data allows more long-term efficient operations in another part of the building. Similarly, there might be temporal variations, for example when the building is used by known, registered people during a typical day, versus times when the building is open to visitors who are not registered. Taken together, this would result in multiple footprints (multiple spatial, temporal and inhabitation-focussed footprints) for the same proposed building that can be compared and contrasted over time as a communication tool between groups of stakeholders with an interest in the design and future inhabitation of that building.

6. CONCLUSION

Adaptive Architecture ecologies at various scales are increasingly driven by personal data, whether that data is provided by inhabitants or measured through technologies embedded into the environment. These combinations of personal data and adaptive architecture will be shaping our future human-building interactions, but they have so far not seen detailed review and analysis. Drawing on the series of envisioning workshops presented in this paper we have highlighted key aspects of the emerging design space in this context. We contribute an exposition and discussion of the temporal and spatial design tensions that arise when adaptive buildings and personal data are interlinked, as well as those design tensions emerging when adaptive buildings are inhabited. We contextualised this within the new European data protection legislation framework, the GDPR. Our discussion of this material has then delivered our second contribution, a re-useable template for how to consider the uncovered tensions for analysis and future design work of adaptive buildings driven by personal data.

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