The Machine Metropolis: Introduction to the Automated City

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Abstract The automation of cities through both mechanisation and digitisation has had a phenomenal impact on our way of life and the design, construction and operation of our cities. This mechanisation has led to the deployment of robotics and 3D-printers on construction sites. Drones are now equipped with cameras that are used to measure the progress of construction works and monitor assets for structural defects. Simultaneously, our cities are increasingly filled with various sensors that extract data from our digital trails, accelerating the datafication of our urban environment. This chapter outlines the broad themes of the book, exploring the impact of technologies of automation on the city in three ways: the automation of the design process to provide optimised solutions to design problems. Second, the automation of construction processes and building maintenance programmes, including advances on how we collect and analyse sensor data. Third, how technologies of automation could potentially impact our way of life in cities, such as how we expand our cities, how we manufacture and fabricate what we need and want, how we utilise urban data to navigate around a city to transport people and goods, or use urban data to make trusted decisions about a city.

Keywords Datafication · Smart city · Automation · Trust · Drones · 3D printing · Sensor data

1 Towards a Braver Automated Future for Cities

Toward the end of 2019 and the first half of 2020, the pandemic of a novel coronavirus swept initially through the Chinese city of Wuhan and then outwards across China before making its effects felt globally. The virulent impact of the disease overloaded international healthcare systems. To meet the health challenge in Wuhan, China mobilised its builders to construct the 1000-bed *Huoshenshan* hospital and the 1600-bed *Leishenshan* hospital, each in under a fortnight (Jancowicz 2020). While
the unique Chinese labour environment contributed to the possibility of such efficient construction time frames, it is the use of prefabrication and modularity—made available through the adoption of technologies of automation in the Chinese construction industry—that allowed the extraordinary short time frames to be achieved.\footnote{The designs for the hospitals were based on a prior hospital built to tackle the SARS-epidemic in 2003 (Ankel 2020).}

Automation in the city is not a novel occurrence. Historical lamp lighters who manually lit streetlamps were replaced with electrified street lighting (Jeffries 2016). Lift attendants who used to manage lifts were replaced with automated lifts. Cars that are equipped with varying levels of automation in parking assistance and adaptive cruise control now operate on our streets. This mechanisation of various functions within the city has progressed to the deployment of robotics and 3D-printers in off-site manufacturing and on construction sites. Drones are now equipped with cameras that are used to measure the progress of construction works (Kemp 2017; Dupont et al. 2017) and monitor assets for structural defects (Zhang et al. 2019). Our cities are increasingly filled with various sensors that extract data from our digital trails. As we interact with these sensors carried as devices on our bodies or embedded in the built environment, we actively bring into our cities a new phase in automation—the move from mechanisation to a digitisation and datafication of urban life. The resultant automation of cities through both mechanisation and digitisation has had a phenomenal impact on our way of life and the design, construction and operation of our cities.

This approach to defining automation as the adoption of increasing layers of technology to drive the city, and the relatively recent integration of digital systems, frame our exploration of the ‘smart city’. Foth et al. note in Chap. 13 (From Automation to Autonomy: Technological Sovereignty for Better Data Care in Smart Cities) that the smart city is a site of ‘fusion of data and automation’, requiring us to consider both the technology and its socio-political impacts. This book explores the impact of technologies of automation on the city in three ways that broadly correspond to the three parts of this book. In Part A, the book explores automation of the design process—how technology has been harnessed to sift through a wide range of design solutions to provide optimised suggestions to a design problem.

The second way in which automation is explored is in the automation of construction processes and building maintenance programmes. Part B of the book investigates how the construction industry can further achieve efficiency gains by deploying technologies of automation in the form of robots, 3D printers, drones on construction sites, and new technologies in the manufacturing processes off-site.

The third way in which automation is presented is how these technologies of automation could potentially impact our way of life in cities. As these technologies of automation are increasingly integrated into the urban fabric, they impact the socio-political landscape of our cities. Part C of the book veers toward a more speculative aspect of future-casting where we consider the impacts of automation on how we expand our cities, how we manufacture and fabricate what we need and want, how we utilise urban data to navigate around a city to transport people and goods, or use
urban data to make trusted decisions about a city. These chapters consider how the deployment of technologies of automation will need to be continuously fine-tuned to address the social norms and values that are emerging in our cities, particularly the privacy of occupants. This requires us to consider how community engagement, our ‘right to the city’ (Lefebvre 1996), and legal reform can be harnessed to automate the city in sensitive and human-centred ways.

Given that the projects captured in this book will sometimes touch on the design process, construction methodologies and the future impact of the deployed technology of automation, there is some overlap between the broad categories of the book. Projects presented in one part of the book will still provide guidance on the impact of the technology in the other two parts. This first chapter serves to introduce the chapters contained within this book and provide context for the design and construction challenges that the authors tackle within their various chapters; and to point to the potential impacts of these technologies that will be explored towards the end of the book.

2 Automation in Solving Design Problems

Part A of this book explores the impact of automation on the search for design solutions to technical briefs. While we are beginning to see a plethora of ways in which automation of the construction process can occur, there is a perception that the creative functions fulfilled by designers (including urban planners, architects, and engineers) are not as vulnerable to replacement by automation.

One of the activities I run in my architecture classes on The Automated City is an exercise where I have my students map out the tasks given to architectural interns and graduate architects. I then ask the students to consider what it would take to automate these tasks. A common perception among the students is that machines are unable to perform design tasks as these are seen to be higher order cognitive functions that are too complex for machines to handle. Their view is reflected in a 2013 study by the University of Oxford which found that the risk to architects of potential replacement by automation sits at 1.8% (Frey and Osborne 2017: 58).

Despite this perception, the process of answering a design brief can be broken down into a number of individual smaller tasks. Some of these tasks could be performed by a machine and to a level of complexity, speed and accuracy that would exceed human ability. The same 2013 Oxford study suggested that Architectural and Civil Drafters had a 52% chance of being replaced by automation processes (Frey and Osborne 2017: 63). Their findings indicate that some of the mechanical tasks that comprise the job of being an architect, engineer or urban planner are more likely to be taken up by a machine at some point in the future.

Almost half a century ago, Cross suggested that automation could be applied to optimise floor plans, suggesting that the ‘tedious calculations to quantify travel time between rooms’ could be readily performed by a machine (Davis 2015 citing Cross 1980). Davis notes that Cross’ research did not lead to better performing buildings as
Cross’ premise of optimised floor plans had little bearing on what was perceived to be a successful building. Instead, technologies of automation in the form of email and other telecommunication devices diminished the importance of an optimised floor plan. The reduction of what constituted a successful building to walking distances between rooms neglected a holistic understanding of how a building is experienced and understood—its materiality and the morphology of its built form, its symbolic capital, and the phenomenology of its spaces, including the soundscape within the city that it inhabits (Wood and Doney 2015; Mattern 2020).

Cross’ lack of success in improving the design of buildings highlights a key point: where the machine augments a human designer’s ability, the design process will fail where it is directed to solving the wrong design problem. Here, the reduction of a successful building to an optimised floor plan was an incorrect framing of the design problem. Despite this, machines have achieved a level of maturity within the field of design such that significant aspects of the design process are now automated through parametric design and other forms of computer modelling.

Parametric design of buildings is the use of computer algorithms to allow a machine to generate possible design solutions based on set rules and variable parameters (Monedero 2000; Alvarado and Muñoz 2012). Such algorithms are used to generate various design permutations, which range from how a building form will look to what internal floor plans would best meet the design requirements. The algorithms can also identify potential solutions to inform the shape of a building’s external surface, such as any openings for windows and doors, or any extrusions like canopies and balconies. Where parametric design is applied on a wider scale, such as urban design, it can be utilised to model setbacks, the impact of privacy demands on urban densities, open space, settlement patterns, and calculate transportation systems that optimise travel paths (von Richthofen et al. 2018).

Hosey (2017) suggests that the design process can be reframed as an initial search through a set of possible design solutions before the process narrows down to key results that answer the technical brief of the design problem or serve the preferences of the designer or client. In the former case, the goal of automating the design process would be to introduce a level of objectivity that is measurable and endlessly customisable. Machines are able to work through the different iterations of a design at high speed and deliver on multiple solutions within a significantly shorter period of time when compared with human designers (Davis 2015 citing the example of Autodesk’s Project Dreamcatcher²).

Where the design solution is required to elicit a desired emotive response from the client, computers with face-tracking software can be trained to read human emotions (Lewis 2019) to determine the actual success of a design. Realeyes, an Emotion Analytics framework that has been trained against a database of 420 million frames of captured human reaction to various stimuli, is an example of how emotional AI

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²Autodesk’s Project Dreamcatcher states on its website that ‘Dreamcatcher is a generative design system that enables designers to craft a definition of their design problem through goals and constraints.’ The project aims to produce a computer system that can ‘generate thousands of design options that all meet [the] specified goals’. https://autodeskresearch.com/projects/dreamcatcher. See also: Sidewalk Labs’ recently announced ‘Delve’. https://hello.delve.sidewalklabs.com.
can potentially augment a machine’s ability to seek out appropriate design solutions. In the case of Realeyes, the database of expressions has been coded against six basic emotions: anger, disgust, fear, happiness, sadness and surprise (Lewis 2019). It is conceivable that machines could, in the future, determine an emotional response of a client without human bias or other subjectivity. However, it appears that the technology is still in its infancy.

Despite this, in the future a machine may be quicker in searching for appropriate design solutions while utilising facial recognition software to collect honest reactions from stakeholders in an emotional AI feedback loop. This Creates a potential automated design process that is far more sophisticated, accurate and efficient than traditional human-based design processes. Even where machines are not used to replace humans and automate tasks, augmentation of the human designer still offers a clear possibility for improvements to the design process, particularly in seeking out appropriate design solutions.

However, the prospects of a machine interacting with an occupant and reading their emotions is not without controversy. Sedenberg and Chuang (2017) observe that emotional AI systems are not infallible and that there are risks of ‘misidentifying individuals, and misattributing particular emotions to individuals’. Further, they observe that the use of emotional AI systems could potentially ‘result in unjustified consumer injury to a consumer’s mental wellbeing’ (Sedenberg and Chuang 2017). As such, it is crucial for us to consider a human-centred approach to designing this human–machine interface. ³

### 2.1 Automation and the Human–Machine Interface

Chapter “2 (Designing Human-Machine Interactions in the Automated City: Methodologies, Considerations, Principles)” by Tomitsch and Hoggenmueller articulates this human-centred approach in examining the human–machine interface in cities. They begin by capturing the layers of automation that impact urban life and shape our understanding of the smart city. By decoupling automation from its more common iteration of robots operating various aspects of the city, they note that automation as a historical process has been the application of technology to drive innovation and to mechanise, and then digitise, urban life. This digitisation of the city is now characterised by constant interactions between the occupant and the larger urban operating platform through embedded robotics and algorithms that operate as ‘city apps’. These city apps take three different forms: physical interfaces such as pedestrian crossing buttons; digital applications that sit on mobile devices; or hybrid systems such as interactive screens in information kiosks.

³For emotional AI systems, information collected on an individual’s emotional state could potentially be categorised as ‘sensitive information’ and treated in a similar manner to private medical information on an individual (Sedenberg and Chuang 2017).
Tomitsch and Hoggenmueller investigate the impact of automation processes on the way in which a city is experienced and understood through human–computer interaction (HCI), providing a case study on an automated system in a smart home. They survey a number of key human-centred design models, include participatory design, action research and design thinking, spiral models, service design, systems thinking, and urban design.

The researchers suggest that this human-centred design approach will guard against the knee-jerk technological optimism that prioritises technological advancement over humans. To assist in the adoption of this design approach, they present a set of principles to guide the prototyping and deployment of technologies of automation to ensure that a human-centred design approach is maintained.

### 2.2 Automation and the Inside-Outside Interface

The next chapter hones in on one aspect of the human–computer interface described in chapter “2 (Designing Human-Machine Interactions in the Automated City: Methodologies, Considerations, Principles)” that operates within the external edge of the building. Gage and Thorne (2005) observe that there is an inflexibility in traditional building management systems where occupants are prevented from controlling their own building environments, from switching on lights, controlling how window blinds operate, to the level of airflow, temperature and humidity. They identify a tension between the occupant subjected to the hierarchical, top-down control of internal environments and the occupant’s desire to directly manage the qualities of the space they inhabit (Gage and Thorne 2005: 169). Technologies developed to address this tension have given rise to interactive facades where an occupant can interface with a ‘local intelligent shading controller and actuator’ within the ecosystem of the internet of things (Gage and Thorne 2005: 170 citing Skelly and Wilkinson 2001). These smart facades allow occupants to exercise their local preferences to control and activate individual components of the smart façade to respond to the local environmental conditions, without mediation of a centralised building management system.

Rowe (2001) observed almost two decades ago that the first domestic robots have been in homes since the mid 1960s. These were pool robots that were ‘mobile and autonomous’, and they were able to fulfil their function of cleaning the pool, filtering the water and detecting when they were outside of the pool. However, it took almost 35 years for robots to leave the swimming pool and be embedded in different parts of our buildings. This delay was due to our lack of structured environments within the fabric of our buildings where robots could operate without having to interact with the full spectrum of complex human behaviour (Rowe 2001). Gage and Thorne (2005: 171) observe that where building facades are designed as a double-skin system, the building envelope can provide this structured environment for robots to safely operate within. These building facades are a specific human–machine interface that also operates as the interface of the internal building spaces with the wider urban environment.
Chapter “3 (Automating Kinetic Screen Design from an Origami Fold)” by Joseph Lim examines the design process for a kinetic screen that is based on an origami fold. He positions the chapter within the field of building automation that has seen the integration of maintenance robots and self-adaptive AI systems in buildings. These intelligent facades sit within a broader spectrum of climate-responsive technologies aimed at mechanising the fenestration of buildings. These range from Menges, Krieg and Reichert’s *HygroSkin* (Menges 2016), to *Edge Monkeys*—robots that operate on the vertical surface of buildings that can be used for maintenance or for adapting building openings and screens to respond to environmental stimuli (Gage and Thorne 2005).

By using the Momotani fold as the basis of his kinematic study, Lim notes that these folds have an expandable quality that allows the façade element to increase its surface area in three axes. The resultant kinetic screen offers significant advantages when deployed such as its potential use as a dynamic heat reflector, shading device, wind baffle, ventilation fin, and means of capturing wind and solar energy. The impact of such a technology of automation can be wider than the building itself, with Lim noting that the dynamic façade elements can contribute to the lighting and acoustics environment of the city.

### 2.3 Automation and the Redistributed Design-Construction Interface

The previous chapter examined the integration of technologies of automation and robots within the built form, and how these robots can augment the occupant’s ability to operate and control their internal environment. This next chapter considers the use of robots prior to building occupancy where they are deployed as part of the design and construction process.

Chapter “4 (From Factory to Site—Designing for Industrial Robots Used in On-Site Construction)” by Luo and Yu continues the examination of technologies of automation with an exploration of robots for on-site construction. They observe that unlike their predecessors that were designed for single functions, modern day industrial robots are ‘open-end customisable platforms’ that have functional flexibility to carry out a variety of tasks and perform complex construction methodologies. As such, these robotic systems are no longer confined to the construction phase of a project but are a key component of the design process. Luo and Yu suggest that this requires us to conceive of both design and construction processes proceeding in parallel, ‘impacting our understanding of building tectonic and the structure of the building industry’.

They present case studies in three different scenarios of on-site construction: concrete casting, brick assembly, and the assemblage and installation of a steel structure. In their first case study, Luo and Yu examine the slip-form fabrication of columns by robotic arm through Smart Dynamic Casting. They observe how the
integration of robots on-site allows for the design process to continue in parallel with the construction process. Where any changes are necessary due to construction on the site, the information is fed back into the design process, with design changes automatically calculated and ‘seamlessly’ programmed back into the construction process, ‘in which conventional human involvement is merely supplementary’.

Despite this observation, Luo and Yu suggest that unlike sterile factory conditions where robots perform repetitive tasks in controlled environments, robots deployed on construction sites need to be guided by human actors to respond to unpredictable environmental conditions and dynamic work sites. They suggest that while robots will continue to play a big role in reducing industry reliance on manual labour, there is still a ‘valued role for humans to exercise creativity and professional expertise’ on construction sites.

3 Automation in Construction and Building Services

Part B of this book proceeds in three sections. The first section considers the use of 3D printing on construction sites. The second section considers the use of drones equipped with an array of sensors to carry out building inspection programmes. The third section observes the impending changes in the way we automate offsite processes to drive new approaches in modular construction.

3.1 3D Printing and Construction

Chapter “5 (3D Printing and Housing: Intellectual Property and Construction Law)” by Wang and Rimmer considers the progress of 3D printing on housing construction from a legal perspective, examining the development of intellectual property activities and the interaction of 3D printing technology with existing and emerging building regulatory frameworks. Their chapter begins with a brief history of 3D printing in the construction industry, before presenting a global survey of 3D printed housing projects through intellectual property activities, such as copyright, design law, patent law, trademark law and trade secrets. The intellectual property activities reveal a variety of approaches to 3D printing and different levels of development and deployment of 3D printing technology across international jurisdictions.

Wang and Rimmer then examine how 3D printed housing projects interact with various building regulatory frameworks as they are translated from digital models to construction sites. The interplay of human labour and on-site 3D printers could be impacted by work health and safety laws, particularly as the lines of liability between designer, project proponent and contractor are potentially blurred in 3D printed construction projects. Contractors utilising 3D printing technology may also find it challenging to comply with building codes that have testing regimes that are unlikely to suit 3D printing methodologies, and where there is limited knowledge of
the printing material properties. However, Wang and Rimmer note that the increased accuracy and transparency over the quantities of materials used permit a highly accurate quantification of the work performed on site. This may offer potential advantages in reducing wastage of building materials and the impact on the environment, and in ensuring that fair payment is paid by the project proponent to the builder for works performed on site.

Wang and Rimmer conclude that the intellectual property activities and emerging building regulatory frameworks indicate an increasing adoption of 3D printing technology in the construction industry. However, they observe that further research is required to ensure that the potential advantages of 3D printing is not curtailed by ‘bureaucratic red-tape, inappropriate testing regimes, and social misconceptions’.

3.2 Drones on Construction Sites

As infrastructure and other building assets are increasingly digitised and equipped with sensors, the capacity to utilise surveillance technologies such as drones, LiDAR and GeoSLAM to measure and produce highly sophisticated and accurate digital models of buildings has been advancing (Counsell and Taylor 2017; Díaz-Vilariño et al. 2017; Sammartano and Spanò 2018). This integration of sensors in the built environment is not just the retrofitting of sensors into existing buildings, such devices are increasingly utilised as part of the construction process to track people on construction sites, enhance safety and to produce a more holistic picture of how resources are being deployed. This has led to a push towards intelligent construction management services that utilise machines to produce precise measurements of progress on site, particularly as human estimates of such quantities can be up to 20 to 30% inaccurate (Ashurst 2017).

Currently, 3D mobile mapping technology and unmanned aerial vehicles (UAVs) (Doherty et al. 2016) help to increase the reach of current sensor technologies in the built environment. For example, 3D mobile mapping technology such as the GeoSLAM ZEB-REVO handheld scanner has been deployed on hazardous sites to allow surveyors to safely capture survey data of derelict structures (Reid 2017). Such devices utilise a form of 3D mobile mapping technology adopted from the robotics industry, known as simultaneous localisation and mapping (SLAM) technology (Sammartano and Spanò 2018). SLAM has traditionally been employed to allow unmanned vehicles to navigate unknown terrains while simultaneously mapping their environment, without the need for GPS (Reid 2017).

In the same vein, 42 per cent of firms in the UK construction sector use drones as part of their business practice (Ashurst 2017). Such drones can be equipped with machine vision to map and monitor construction sites (Liu 2018; Vincent 2018), and where these drones are equipped with radio frequency identification (RFID) technology, they can also be applied to accurately map out metallic products deployed on a site (e.g. metal pipework, reinforcing plates, etc.) (Ashurst 2017). This real-time aerial surveillance of sites opens up opportunities to operate robotic excavators and
machines, track progress and quantities of spoil in real time (Dupont et al. 2017). In 2018, Japanese construction firm Komatsu partnered with Skycatch (a joint Japanese-US private enterprise) to expand its ‘Smart Construction’ service (Daniel 2018). The service provides ‘high-precision’ site mapping, conversion of 2D drawings to 3D drawings, ‘construction plan simulations; and intelligent machine control’ (Daniel 2018). Accordingly, these sensor technologies allow for more accurate assessments of the work performed, make inspection and monitoring work safer, particularly as assets become taller, more complex or difficult to access.

The following two chapters consider the use of drones, machine vision and AI systems to carry out building inspections and other maintenance activities for buildings. In particular, the advances shown in the AI systems featured demonstrate the advancement of image capture technology utilised to capture site surveys and track construction progress, allowing the data feed to drive decision-making on building assets.

Chapter “6 (Automation in Structural Health Monitoring of Transport Infrastructure)” examines the automation of structural health monitoring (SHM) for road infrastructure. Zhang et al. observe that as an increasing number of bridges approach their 50-year life span, there is a crucial need to ensure adequate processes are in place to monitor and maintain their structural performance. They assert that conventional visual inspections are labour-intensive, time-consuming and costly, and are ‘always subjective and can produce unreliable results’. As such, Zhang et al. suggest that automation of SHM programmes will enable more efficient monitoring to occur. They note that this automation of SHM has three aspects, namely the automation of data acquisition, data processing for both external and internal defects, and life-cycle assessment.

Zhang et al., investigate the use of unmanned aerial vehicles (UAV) in data acquisition where a UAV is deployed to take images of the external surface of infrastructure. Following the acquisition of the photographic images, the next step involves automation of the digital image processing function. Zhang et al. examine computer vision-based health assessments for external defects. These include digital imaging processing techniques that detect cracks utilising the gradient differences within the pixels of the collected images; frequency domain techniques; and novel filtering and morphology processes that aim to mitigate noise contained in the collected images that may affect the accuracy of crack detection across both concrete and asphalt surfaces. For the detection of internal defects, Zhang et al. suggest that all non-destructive testing (NDT) technologies available have limitations. Accordingly, these NDT technologies will need to be deployed with another testing process in order to obtain an appraisal of the internal structural health of an asset. Such NDTs include ground penetrating radar, infrared thermography, impact echo, ultrasound pulse velocity, ultrasonic surface waves, interferometric radar system, and acoustic emission.

Automation of the assessment process concerning the life-cycle performance of a structure requires the generation of a deterioration model to provide an accurate prediction of ongoing damage and potential structural failure. Zhang et al. consider three different ways in which a deterioration model can be calculated based on
the reliability-based analysis method, general algorithms, and artificial intelligence. They present various AI techniques, such as machine learning, case-based reasoning and artificial neural networks (ANN) to assess the magnitude of structural impairment. Zhang et al. observe that ANN is particularly important in the automation of SHM given the limited historical training data, with ANN serving as a mechanism to ‘generate past condition ratings to predict future ratings’ of road infrastructure.

Chapter “7 (Framework for Automated UAV-Based Inspection of External Building Façades)” continues the examination of UAV-based structural monitoring, turning the focus onto building facades. Liu et al., present an extensive review of the development and challenges of UAV-based techniques within the practice of civil engineering. The team presents a case study on a vision-based inspection of a building façade conducted by UAV, setting out their framework to manage the workflow of data acquisition and data processing. They make a similar observation to Zhang et al. that the deployment of UAV inspection processes, incorporating advanced data processing systems, will permit ‘accurate diagnosis of defects and remove subjective human assessment’.

Liu et al., also present a case study utilizing UAV-driven data acquisition to create photogrammetric surveys and 3D reconstructions. However, they suggest that further studies could be undertaken to optimize flight paths while accounting for both dynamic environmental factors and task-related considerations that require the UAV to avoid any ornamentation or architectural features to minimise occlusions. They note that autonomous navigation of UAV-driven data acquisition has not yet been realised and an experienced pilot or second operator is typically required to assist to ensure accurate navigation.

Both chapters indicate that this layered use of technologies of automation in the area of SHM is maturing. There are clear advantages in the deployment of drones to capture images of an existing building asset, along with the use of AI systems to process the collected data and model the state of its structural health and prediction of any future deterioration, including increased accuracy and a means of reducing human bias in assessments.

3.3 Pre-Fabrication and Modularity

Chapter “8 (Design and Automation for Prefabricated Prefinished Volumetric Construction in Tall Buildings)” by Liew and Chua turns our attention to off-site prefabrication and modularity. They explore how current technologies of automation used in the construction industry can further reduce on-site labour and increase efficiency in the construction of high-rise buildings, particularly in land-scarce urban environments.

Liew and Chua consider how the construction industry can embrace the adoption of advanced technologies to improve existing construction methodology. Modern modular construction—particularly Prefabricated Prefinished Volumetric Construction (PPVC)—offers significant advantages in that the modules, along with integrated
services and fittings, are completed off-site in controlled environments. However, despite the efficiencies and potential cost savings offered through off-site fabrication of these modules, transportation and hoisting of these modules can pose significant challenges. They observe two types of modular systems, each with its own set of advantages and disadvantages: first, load bearing wall modules are generally fabricated using concrete, making them heavier and slower to install; second, corner supported modules are typically made of steel that has a higher risk of corrosion and lower fire resistance.

Notably, Liew and Chua observe that while the industry is investing heavily in automation technologies, there is a lack of an accompanying highly-skilled workforce, which is still crucial to the construction of modular units. The sustained dependence on manual labour that automation attempts to reduce still creates a potential for errors to occur in fabrication that lead to eccentric loading of modules and other serviceability issues.

Liew and Chua suggest that more technologies automating lifting and installation methods should be carefully designed and deployed to minimise use of manual labour. Installation of the modules should also be minimised through innovative inter-module connections to allow modular construction to be deployed at greater heights. They suggest that modernisation of construction technology needs to embrace new materiality in the fabrication of these modules, recommending the use of composite concrete and steel modules. These hybrid modules will allow a wider range of automated processes to be deployed to lift, install and build in different commercial and industrial contexts, such as factories that often require larger column-free internal spaces and commercial towers.

4 Automating Urban Life Through Data and Infrastructure

Part C of the book examines how urban life could further be impacted by technologies of automation.

The interaction of designers with technologies of automation have often provided new conceptions of the city. In the 1960s and 70s, the works of Archigram in the UK and the Metabolists in Japan celebrated the idea of modularity as a means of realising an adaptable and re-programmable city. Peter Cook’s Plug-in city was designed to contain cranes that formed part of the superstructure. These cranes would be used to ‘plug-in’ various modules that would then connect with a superstructure carrying an array of building services. Where the particular spatial function served by the module was no longer required or desirable, the crane embedded in the superstructure could be used to unplug the module and replace it with a differently programmed module. The Nakagin capsule tower in Tokyo by the Japanese Metabolist Kisho Kurokawa was designed around a similar concept. More recent iterations of this concept include Google’s new campus designed by BIG and Heatherwick that takes on this idea and replaces the crane in the Plug-in City with crane robots (or ‘crabots’) (Rosenfield 2015). These crabots would build the campus and continue to remain a
part of the operations fabric of the campus. Where a different spatial configuration is required, the crabots would allow ‘limitless, easy, and affordable’ reconfiguration of the spatial programs of the new campus. In such a way, the space would be ‘hackable’ (Rosenfield 2015).

4.1 Modular Cities on Water

Chapter “9 (Automation of Land Expansion: Prefabrication of Floating Platforms for Expansion of Cities onto Adjacent Water Bodies)” by Wang and Jung takes the exploration of prefinished modularisation one step further, exploring the impact of how automation in large infrastructure developments can be utilised to enable cities to expand sensitively over adjacent water bodies. Modular construction methods allow Very Large Floating Structures (VLFS) to be fabricated across multiple sites in controlled environments that potentially enable short time frames and cost-effective delivery of large infrastructure projects that are often plagued with cost blowouts and significant delays. Arguably, these floating modules can be reassembled and reconfigured, and when paired with marine drones, could potentially produce a similar hackable floating urban installation to Google’s proposed new campus with its crabots.

Wang and Jung explore three areas in which VLFS can be deployed as floating infrastructure, such as bridges, power stations, etc., places of recreation and commerce, and as standalone residential communities. They examine three key case studies: the Mega Float in Japan, a project that was built to study the feasibility of a floating airport runway in Tokyo Bay for Kansai International Airport; a floating passenger terminal in South Korea; and the largest floating performance stage in the world, located at Marina Bay, Singapore. They observe that as VLFS technology is deployed as a more environmentally sustainable solution to land reclamation in land-scarce coastal cities, the increased complexity of these projects will necessitate more sophisticated technologies of automation to allow complex connections and assembly to occur on the water. Such technologies include the use of 3D scanning, drone photogrammetry and other UAVs equipped with machine vision, as well as the use of common data environments that allow modelling from data extracted across all disciplines involved in the project.

4.2 Fabricated Cities

Technologies of automation allow us to embrace new materials in construction. There has been an ongoing trend of exploring new materiality in pavilions. For example, in 2016, students from the University of Stuttgart utilised robots to bend and stitch together shells of laminated beech plywood. Inspired by the sea urchin, the interdisciplinary team comprised students drawn across architecture, engineering, biology
and palaeontology specialties (Menges 2016). The novel use of an industrial sewing machine controlled by software was used to create ‘stitched joints [that] transfer tensile forces between the segments, playing a similar role to the fibrous connections found between the plates of a sea urchin’s shell’ (Mairs 2016). New materials and construction methodologies have allowed us to reconceptualise the way in which we build and revitalise the city, and the way we consume goods.

Chapter “10 (Automating Fab Cities: 3D Printing and Urban Renewal)” by Matthew Rimmer investigates the phenomenon of Fabricated Cities (Fab City) and the potential socio-political impact of 3D printing technology. Rimmer examines the ten principles of the Fab City Manifesto that capture environmental sustainability objectives to inclusivity and equitable access to 3D printed outputs. These principles include a focus on local manufacture and culture, such as 3D printed architectural elements that can be utilised for the restoration of historical sites and other cultural heritage purposes.

Another key principle within the Fab City Manifesto advocates for the resilience of cities through a human-centred approach to the deployment of technologies of automation, such as autonomous vehicles, artificial intelligence and robots. The principles also advocate for the adoption of open source principles and open data, presenting the example of citizens printing their own open-source sensors to measure environmental conditions.

Rimmer also examines how 3D printing technology is driving policy and regulation in the expansion of cities. He cites Dubai’s 3D Printing Strategy that will require every new building to be 25% 3D printed from 2025. 3D printing technology also has clear military application, where 3D printers can be utilised to construct temporary facilities and housing in dangerous conditions. Rimmer suggests that 3D printing technology is ripe for deployment in disaster relief where this could be used to speedily build emergency housing, and structures to maintain business continuity to add to the resilience of cities.

4.3 Automated Vehicles and the City

Chapter “11 (Connected and Automated Vehicles: Opportunities and Challenges for Transportation Systems, Smart Cities, and Societies)” by Sharma and Zheng explores the way in which connected and/or automated vehicles (CAVs) will fundamentally change the way in which we interact with cities. CAVs are automated vehicles with communication capability. The chapter considers how CAVs can change the way we transport people and goods more safely, efficiently and with greater connectivity to interoperable wireless communication networks. With connected vehicles, the driver retains control over the vehicle, including movements changing between lanes and distance from the vehicle in front. The communication capabilities of the vehicle function to augment the driver’s abilities and are designed to convey traffic data via vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communication. In the case of automated or autonomous vehicles, vehicles
are designed to minimise or remove the need for human intervention during the vehicle’s journey.

From a road transport perspective, CAV technology promises to reduce traffic congestion, increase road capacity, enhance traffic stability, reduce vehicle emissions and its harmful effect on air quality, and improve fuel economy. From a societal public policy perspective, CAVs have the potential to improve mobility for the elderly, the young, and people with a physical disability. Additionally, with appropriate planning and implementation, CAVs can enhance the overall accessibility of a city and reduce travel cost.

Sharma and Zheng observe five major barriers for the deployment of CAVs. First, given the evolutionary nature of this technology of automation, there will be a transition period where CAVs will need to share the roads with traditional vehicles. The resultant mixed traffic flow will require the CAV to navigate and tactically respond to human driver error from non-CAVs. They note that even where there is a significant deployment of CAVs on the road, where CAVs are inefficiently distributed through the mixed traffic flows, there will be little gain in congestion reduction and safety. Second, there is likely to be a significant disruption to the car manufacturing industry, transportation sector and insurance industry. Sharma and Zheng point to research indicating a high cost burden on displaced workers from the transport sector and potential diminution of the insurance industry by up to 60%.

Third, ethical issues arise when machines are required to calculate a travel trajectory that may lead to injury or fatality. While guidelines are emerging to enable designers to program automated decision-making functions that attempt to resolve this trolley problem ‘[independently] of any personal feature bias’, there does not appear to be consensus or clarity as to the appropriate values and moral choices that will need to be designed and coded into these machines. Fourth, regulatory frameworks around the deployment of CAVs are still emerging, with various jurisdictions adopting different approaches. This creates significant complexity for designers who will need to engage with the variety of statutory obligations.

Finally, the sensorised data associated with CAVs and the collection, transmission, storage and subsequent use of such data can lead to serious privacy and security issues, underscoring the numerous complicated regulatory and ethical issues still at play. Currently, given the limited ethical guidelines and regulatory frameworks that govern CAVs, there is a need for a wider consideration on how data is collected, used and owned in order for us to integrate technologies of automation such as CAVs in our cities.

5 Privacy of the Occupant Within Digital Representations of the City

The digitisation of cities and the use of data drawn from sensors embedded or located in the urban environment (‘urban data’) has provided us with new ways of collecting
data and modelling what is occurring in the city. These digital representations of the
city permit a wide range of decisions that go beyond the design, construction and
operation of cities, to disrupt and govern urban life.

The following three chapters consider the socio-political impact that technolo-
gies of automation have on occupant privacy in the city. As these technologies are
designed to collect increasingly detailed and varied data sets from the digital trails
of occupants, there is an urgent need to consider how power is decentralised through
new technological infrastructures such as the blockchain; how we can empower citi-
zens through data transparency, data ethics and improved data literacy; and how we
can trust these technologies and the public and private users of collected data.

Chapter “12 (Smart Cities as Panopticon: Highlighting Blockchain’s Potential for
Smart Cities Through Competing Narratives)” by Robb and Deane considers the
manner in which data collection practices in smart cities create a power imbalance
between private and public users of collected data and the occupants subjected to
surveillance. However, rather than a surveillance structure with power concentrated
in a centralised authority, Robb and Deane examine the decentralisation that has
occurred through blockchain technology. They suggest that the blockchain subverts
the current narrative of a centralised surveillance structure to dispersed surveillance
reflective of a mature version of Jeremy Bentham’s panoptican.

Robb and Deane observe that the blockchain enables ‘participants in the commu-
nity [to still develop and use] forms of self-surveillance to hold themselves and others
accountable to the rules and standards that the community itself decided upon’. While
Robb and Deane provide a detailed explanation of the blockchain in their chapter,
in order to provide context to this observed decentralisation of power and surveil-
lance structures explored in their chapter, the salient features of the blockchain are
presented briefly below.

The blockchain exists as a distributed ledger that is duplicated across each node
(say, a computer) on a network. The ledger records and validates interactions on
the blockchain by majority consensus of the nodes on the network, which allows
interactions (or transactions) to occur without a trusted intermediary (Efanov and
Roschin 2018; Wang 2018). This results in self-surveillance within the blockchain
network and (in reference at least to the Bitcoin blockchain):

…demonstrates that a distributed network with no one in charge can govern itself well
enough to avoid collapse and scale in value over an extended period. Trust, which previously
required either the delegation of power or tight-knit relationships, can arise from a collection
of independent actors running open-source software (Werbach 2018: 11).

The blockchain is also an underlying infrastructure for ‘smart contracts’, which are
computer protocols that are built on the agreed commercial obligations negotiated
between two or more parties. These computer codes contain rules that automate
certain interactions within the contract according to agreed parameters and outcomes.
Where a particular condition under the smart contract is met (for example, where
the smart contract detects that one of the parties to the contract has performed their
legal obligation), the blockchain can verify that the condition or legal obligation
has been met without the need for validation through a central authority or trusted
intermediary. Where the condition is met, the blockchain would trigger the automated performance of the coded interaction in response to the validated data.

However, in order for information outside of the blockchain network (‘off-chain information’) to get onto the blockchain, an ‘oracle’ (a data feed or agent that collects and verifies ‘real-world’ data) is required to push trusted data onto the blockchain. Robb and Deane observe that sensors connected in the Internet of Things can act as trusted oracles, pushing off-chain information onto the blockchain. Likewise, other sensors in the built environment, such as the drones and other technologies of automation described in chapters “6 (Automation in Structural Health Monitoring of Transport Infrastructure)” and “7 (Framework for Automated UAV-Based Inspection of External Building Façades)”, can also serve as oracles pushing collected data onto the blockchain.

The question arises as to whether data extracted from our sensors can be readily trusted, even where it is pushed from a trusted source acting as an oracle to the blockchain. These sensors and the blockchain itself are ‘designed, implemented, used by humans. Subjective intent remains relevant even when expressed through objective code’ (Werbach 2018: 6). Similarly, Foth et al. (see Chap. 13 (From Automation to Autonomy: Technological Sovereignty for Better Data Care in Smart Cities)) observe that data is ‘contestable, socially contextual, and complex’. However, in order for such data to be scrutinised, there needs to be data transparency, access, and education to enhance data literacy.

Chapter “13 (From Automation to Autonomy: Technological Sovereignty for Better Data Care in Smart Cities)” by Foth et al. continues the examination of the impact of surveillance technology on the city and the privacy of the urban occupant. They provide a critical review of how urban data collection has been a part of decision-making and intervention in the city since classical antiquity, through the London Cholera Epidemic of 1854, and in its expanded iteration as private-led Surveillance Capitalism—where interventions using Big Data analysis is harnessed to ‘maximise consumption and profits’. By comparing two case studies: the recently shelved Waterfront Toronto by Sidewalk Labs and the city of Barcelona, Foth et al. observe that where cities adopt a human-centric approach to data, this enhances the social licence given to city administrators to make decisions on the data, allowing the great potential for the data collected from our cities to improve urban life.

However, Foth et al. suggest that for data to be used ‘for the common good’, there needs to be a realignment of the surveillance relationship between data collectors and occupants. Occupants need to be ‘empowered [to] understand how their data is used’. They note that technological sovereignty and data sovereignty gives occupants control over their data and over technologies of automation built to exploit such data.

Foth et al. introduce their vision for city-based data hubs that would be available to occupants as a resource and infrastructure to support occupants to understand how their data is being collected, used and sold. They suggest the hub would be utilised in four different ways, presenting usage scenarios for each configuration. First, the hub could operate as a clinic to enable occupants to seek out ‘in-house data scientists’ for consultations on their data practices. Second, the hub would host seminars open to the public to empower occupants to undergo digital literacy training. Third, the hub
would act as a lab to allow the creation of citizen-led digital offerings that are ‘focused on open platforms and citizen engagement’. It is envisaged that this goal of widening participation through community engagement will increase the interoperability of data services and distribute any efficiency and effectiveness gains across a wider and more diverse group of stakeholders. Fourth, the hub would act as a studio that will enable studio groups drawn from across government, industry and occupant communities to examine smart city technology proposals and act as an evaluation panel to assess and direct the data future of the city.

Chapter “14 (Automating Trustworthiness in Digital Twins)” by Wang and Burdon examines the emerging technology of digital twins. Digital twins are virtual models of the physical built environment that are connected to real-time information drawn from sensors embedded in the built environment or from sensorised mobile devices. They observe that data collected from the built environment through surveillance practices enables city administrators to predict occupant behaviour and execute policies that drive desired behaviours, often without an ability for occupants to participate in the decision-making process. These surveillance practices supporting automated decision systems within the digital twin are thus opaque to occupants, subjecting occupants to a black box approach to city-making and urban life.

In response to these surveillance practices, Wang and Burdon offer an alternate approach to the human-centred design principles discussed in chapter “2 (Designing Human-Machine Interactions in the Automated City: Methodologies, Considerations, Principles)”. By applying a conceptual framework of trustworthiness to their examination of the digital twin, Wang and Burdon suggest that technologies of automation need to demonstrate the elements of trustworthiness: ability, integrity and benevolence. They argue that adopting an information privacy law approach to consider crucial privacy protections for the occupant will articulate a new form of Lefebvre’s ‘right to the city’. This right to the city seeks to protect space for self-hood development and allow an occupant to be an active participant in urban life. The resultant creation of space within an environment of surveillance prioritises the privacy of the occupant and allows the digital twin to demonstrate benevolence. Wang and Burdon posit that this articulation of privacy as a value then flows through to the other elements of trustworthiness, allowing the demonstration of value congruence that indicates integrity, and technical competence that demonstrates ability.

6 The Automated Way Forward

Luo and Yu (Chapter 4 (From Factory to Site—Designing for Industrial Robots Used in On-Site Construction)) observe that the truly revolutionary aspect of bringing robots out of factory settings and onto construction sites is that it provides opportunities for collaboration across different disciplines. Their observations are not limited to robots. This ability to draw knowledge across information pools has always been a part of the automation process of the city—where different disciplines interact within
the complex environment of the city to create innovative ways of mechanising and digitising our way of life.

Likewise, the increasing datafication of our cities and our growing appetite for large datasets that offer a glimmer of potential social and commercial benefits has drawn together smart city proponents from across public, private and civic sectors. This has seen the development of common data environments within the construction industry that include Building Information Modelling (BIM) and digital twins, and is changing the ‘traditional approach of... working on separate information pools typically with different and incompatible software technologies’ (Smith 2013: 4). This collaboration enables greater exchange of new learnings across knowledge silos to provide a holistic, multi-disciplinary approach to the design of smart cities and their commercial and socio-political issues. Collaboration across technical disciplines, along with automated data processing systems will not just allow project proponents to ‘gain business intelligence about [the asset’s] operations, to forecast their future needs, and to develop new revenue streams’ (BuildingSmart Australasia 2019: 3), such collaboration also provides a way for us to consider the broader issues of how we can use such data to improve urban life, and make our systems more open and trustworthy.

This book surveys the use of city apps, robots that operate buildings and fabricate structural elements, 3D-printing, drones, advanced prefabricated modules, sensors, and automated decision-making frameworks in cities. It highlights the latest advancements in the use of automation in the design, construction and operation of buildings, and the impact of such technologies on the wider urban environment and legal frameworks. In this manner, the book contributes to the growing literature on smart cities, and continues the conversation captured in the Springer series Advances in 21st Century Human Settlements. This Springer series has covered in detail other dimensions of smart cities and the integration of technologies in titles such as ‘Smart Living for Smart Cities’ (Vinod Kumar 2020), ‘New Urban Agenda in Asia–Pacific: Governance for Sustainable and Inclusive Cities’ (Dahiya and Das 2020) and ‘E-Democracy for Smart Cities’ (Vinod Kumar 2017). It is envisaged that the book will provide a useful reference for further research and development in the area of automation in design and construction, enabling architects, engineers, contractors, project managers, superintendents, policy-makers and legal practitioners to make informed decisions about the automation of the city and its processes.

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