COMPLEX URBAN FUTURES: DESIGN SCIENCE FOR FLUX TERRITORIES

The 21st Century commences with cities as the nexus between an urban age, the fourth industrial revolution and the tipping point for catastrophic climate change. The need for sustainable future cities has never been more critical. The professions and disciplines involved in the design of future cities appear powerless in the face of the complexities involved, the diminishing role of the designer as an instigator of change in the face of quantifiable economic priorities and the oxymoron of sustainable development.

The default passive position taken by most designers in adherence to or intellectual manipulation of existing minimal regulatory frameworks pushes the responsibility for sustainability back towards government. While this is a form of capitulation, the root vulnerabilities based on the difficulties of adopting a critical position that can impact negatively on one's selected vocation are exacerbated by contradictions presented in the idea of sustainable development and the related lack of understanding of the implications of design propositions. This contested space is illustrated through opposing and parallel interpretations of sustainable development, e.g. as a strategy based on recognizing the limitations of growth in the context of unrenewable resources[1] and/or the United Nations economic perspective setting out a significant number of its Sustainable Development Goals (SDGs) around growth and prosperity[2.]

The promise of anticipated technological solutions for urban sustainability – proliferated through Smart City, IoT and Big Data perspectives – continues to encourage a business-as-usual approach to the design of future cities. There is a limited amount of alternative engagement with designed futures through the acknowledgement that more information can lead to more informed decisions, some optimization-based efficiencies and advances in automation. However, the majority of designers continue to concentrate on aesthetics and immediate functionality rather than engagement with challenges at multiple scales. Even the designers deliberately engaged in attempts to reduce the negative impacts of the built environment on climate change are limited to material and functional specifications aimed at reducing the potential damage caused at a local level.

Setting aside the need to redefine the design professions as ethical vocations that need to contribute towards sustainable future cities for another day, the entry point for designers wishing to contribute remains limited due to the overwhelming cognitive blocks in confronting urban sustainability in relation to climate change. The lack of engagement stems from deficiencies in the ability to usefully comprehend the implications of design contributions within the complex, multiscale, temporal and emergent phenomena that constitute the contemporary urban process, resulting in a wicked problem[3] that defies clear definition.

A Research based Design Perspective

Engaging with Complex Systems

Urban Transformations is an emergent interdisciplinary field of research combining complex systems and urban studies. The methodological developments in this area encourage engagement with new opportunities advantaging desirable transitions toward sustainable futures. While focused on socio-economic research, the emphasis on the consideration of real-world-impact of disruptive and projected technologies and urban phenomena provides a useful basis for the development of an alternative ‘design system’.

Engagement with complex systems from an urban transformations perspective enables the understanding of the role of interventions within larger temporal systems with existing dynamics. This is as essential for ‘design systems’ engaging with climate change as it is for influencing trajectories of socio-technical transitions such as the growth of cyber-physical systems and automation based on urban data collection and analysis.

Complexity Planning and Urbanism

The Complexity, Planning and Urbanism (CPU) group consists of the CPU-Lab and CPU-Ai design masters, with a founding role in the transdisciplinary ESRC research network DACAS (Data and Cities as Complex Adaptive Systems) spanning Japan, China, Brazil and the UK. The CPU-Lab is an externally funded research laboratory at the Manchester School of Architecture, where urban transformation is researched by combining complexity theories and the development of new digital tools allowing simulation and experimentation of previously impracticable temporal urban phenomena. As complex systems are an interdisciplinary area of research, concepts from physics, economics, ecology, sociology and computer science are integrated into an evolving body of knowledge aimed at understanding real-world phenomena characterised by temporal change, unpredictability, adaptation and evolution. The wide relevance of the research is demonstrated through the variety of funded research undertaken on ICT enabled sustainable Smart Cities, Connected Autonomous Vehicle (CAV) futures and the use of IoT data for more agile governance.

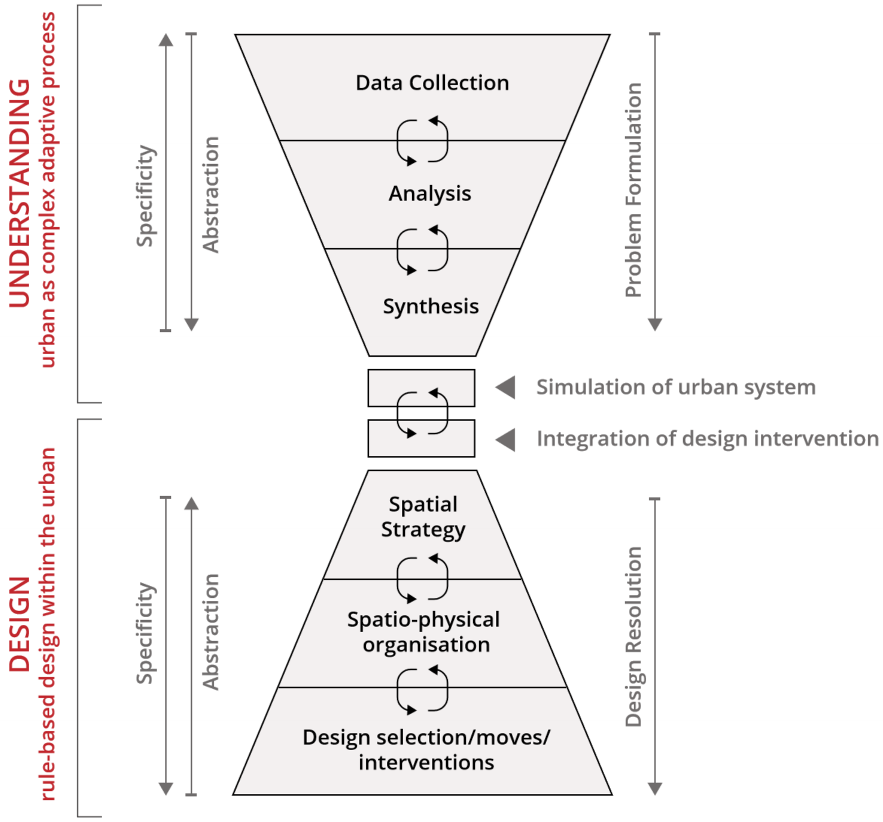
The designers and researchers of the Complexity, Planning and Urbanism (CPU) group have progressed a design science research approach for positioning urban and architectural interventions within a computationally enhanced systemic formulation of the design problem. This 'design system' purposefully centralizes the often ignored or superficial consideration of multi-scale temporal dynamics, disruptive possibilities and relational considerations of the urban process. The urban is a complex adaptive process[4], understanding existing trajectories of change and influencing them towards desirable futures through design requires an engagement with the competing, contradictory, non-linear, emergent, self-organising and open-ended phenomena that are fundamental to this. Rather than operating from separated positions for research and design, CPU explores the space between design and science by merging the real and the artificial through future studies, data analysis, computational simulation, digital participation and research into cities as complex adaptive systems.

CPU-Ai (the design masters) orientates the design studio in architectural education specifically towards learning and formulating new approaches rather than reusing tested methods without modifications on new problems. This builds the capacity for computation enabled complexity-based design thinking in future designers over a two-year immersive process. Design projects make use of information from multiple sources and knowledge from the sciences to translate theoretical concepts involving complexity, resilience and self-organisation into spatially relevant design strategies. The cognition of systemic urban processes over time, knowable disruptions due to technological transitions and the interconnectedness of complex phenomenon lead to an understanding of urban processes, where outcomes cannot be directly or fully controlled through intentional design interventions. This forces alternative positions and methods for the introduction of design towards sustainable futures, enabling engagement with otherwise problematic conditions and transformations.

THE ROLE OF COMPUTATION

Emerging methods of applied computation play an essential role in the consideration of architectural and urban design interventions situated within dynamic urban systems. The potential of the fourth industrial revolution lies in a designer's ability to utilise computer simulation, gamification, AI, automation, VR, and computer-generated design to engage with complex phenomena such as multi-dimensional interactions and feedback cycles between interconnected urban factors. Developing capacity in constructing custom computational models incorporating problem-specific processes requires synthesis of multiple new skills. Attainment of an ability to explicitly model, analyse and dynamically simulate selected urban systems precedes an enhanced awareness of the changes and contradictions in the spatio-temporal processes within the larger systems relevant to any intervention. New interventions are typically introduced as various types of rule-based elements that impact on the process of simulated urban systems which unfold over time. The 'design system' (Figure CH.01) enables the exploration of alternative proposals within simulated urban processes that have identifiable dynamics in play. The construction of such computational thought experiments forces the designer to consider specific relationships and dynamics that play a part in open ended urban systems while understanding the strategic possibilities and limitations of their own specific influence on the system.

THE DESIGN SYSTEM



[Figure CH.01: The design system itself is conceived as an amalgamation of three interactive areas.]

The 'design system' can be understood as three relational areas consisting of 'problem formulation', 'simulation' and 'design resolution' (Figure CH.01). Each of these areas has multiple internal components with feedback loops, iterations and operational possibilities defined with reference to theory-based concepts from the theoretical framework.

Problem Formulation

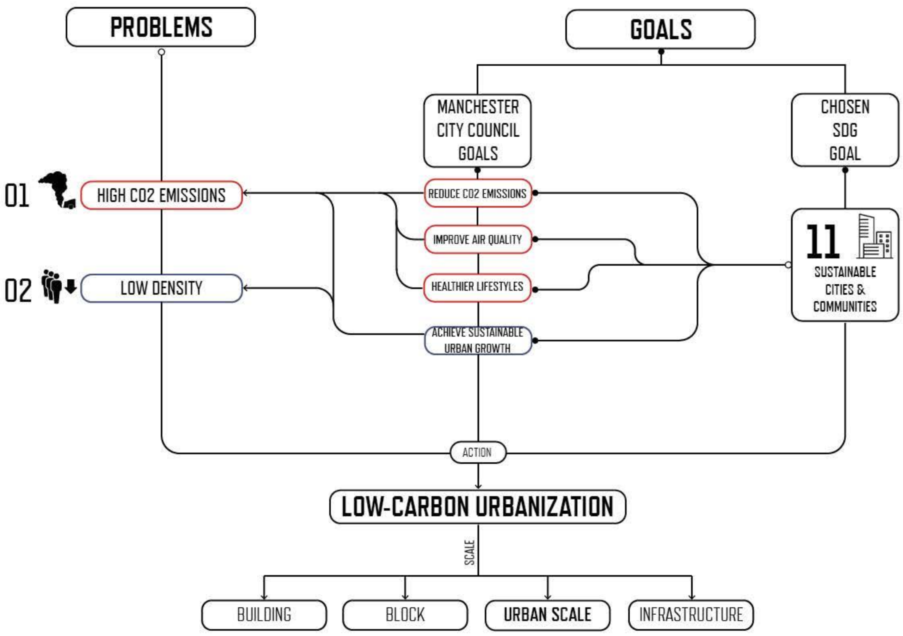
The ‘design system’ developed adopts a complex systems perspective as an overarching theoretical framework for all areas. The formulation of a design problem using this lens becomes essential to the design position. The process of problem formulation involves gathering relevant information and data, problem identification based on context and identifiable issues, development of an understanding of the problem in the urban context and definition of desirable goals with stakeholders (ranging from government and local authorities to funders and local urban dwellers). The synthesis of multiple potentially competing aspects of change and desire as temporal possibilities situates hybrid socio-physical processes within a system of systems context comprising of multiple participants, motivations and physical space. Spatial design proposals are aimed at modifying the potential forces of influence and interactions within the simulated complex urban process.

Airbnb Data Analysis: Disruptive technological trends

[Figure CH:02: Simulation based on use of Airbnb and Zoopla data to extrapolate housing price changes in Manchester by Mahmud Tantoush, Alex Macbeth and Raden Norfiqri.]

The project critically investigated property price scenarios in Manchester based on the growth of digital 'sharing economies'. The technological disruption of increasingly bottom-up E-commerce practices was explored through API based data capture, correlational analysis, and temporal geolocated visualisation of Airbnb and Zoopla data. The findings were extrapolated in a simulation to understand projected outcomes until 2050. Findings such as students being priced out of the 'Manchester Corridor' in future scenarios was utilised to formulate the problem and select design strategies aimed at addressing this possibility.

Low Carbon Urbanisation – Walkable activity-based design



[Figure CH.03: Design problem formulation for low carbon urbanisation by Sevdalina Stoyanova and Adrian Dimov.]

The project was based on a multi-criteria analysis with future development positioned within the city and UN (SDG-11) goals aimed at net-zero futures. It spatialised theoretical applications of centrality, density and compactness to enable exploration of highly connected clusters based on walkability and proximity (e.g. to work and amenities). The computational approach generated multiple urban development scenarios in relation to low-carbon urbanisation indicators while problematising the 'known-unknown' of a future residential population demands by developing and using a synthetic population of intelligent computational agents (an applied use of AI research).

Simulated Urban Systems and Simulated Design Interventions

In order to merge design perspectives – the intention to change the status quo or existing trajectories - with models of existing urban systems, two types of computational simulations have to be facilitated. The first is based on models enabling computational simulations of the targeted urban systems relevant to the problem formulated and the second on rule-based models testing computational simulations of design interventions - that do not yet exist - within the simulated urban systems.

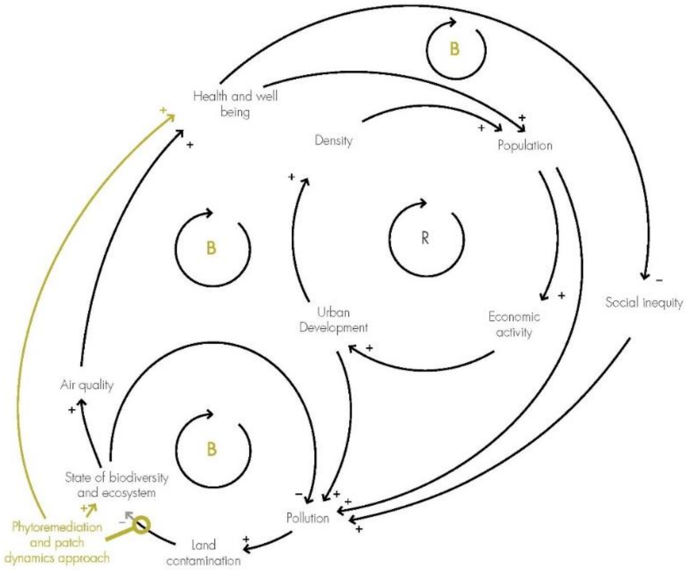
Mental models or mental simulations have been used previously to think about future conditions that are not observable in the world 'out there' based on design interventions. However, computational simulation results in an alternative process and provides its own pedagogic and cognitive value. Mental models/simulations incorporate implicit or hidden assumptions, whereas computational models and simulations of urban systems are necessarily explicit. The "assumptions are laid out in detail, so we can study exactly what they entail." [5]

Constructing a computational simulation is an intellectual task requiring synthesis of targeted urban systems and potential relationships between these and new design interventions. For a simulation to execute, the details of relevant processes must be programmed and translated to computer code. This requires consideration of specific relationships and dynamics that might play a part in the behaviour of modelled open-ended urban systems. There is also the need to strategically identify the specific points of interaction that hold the potential for new design interventions to exert influence.

Our perspective on computational simulation consists of algorithmic models of complex urban systems and their dynamic processes and feedback cycles over time. This is distinct from the typical reference to 'simulation' and 'model' in architecture as representations of proposals and the built environment in the form of architectural drawing, digital or physical

3D representational model[6] or visualisation, flythrough and walkthrough. The initial computational simulation of urban systems provides a basis for design orientated models and simulations aimed at testing alternative rule-based designs and interventions. The notion of ‘simulation’ from architectural research used here is to examine proposed spatial strategies, organizations and design interventions, “to ’preview' identified future scenarios” [7].

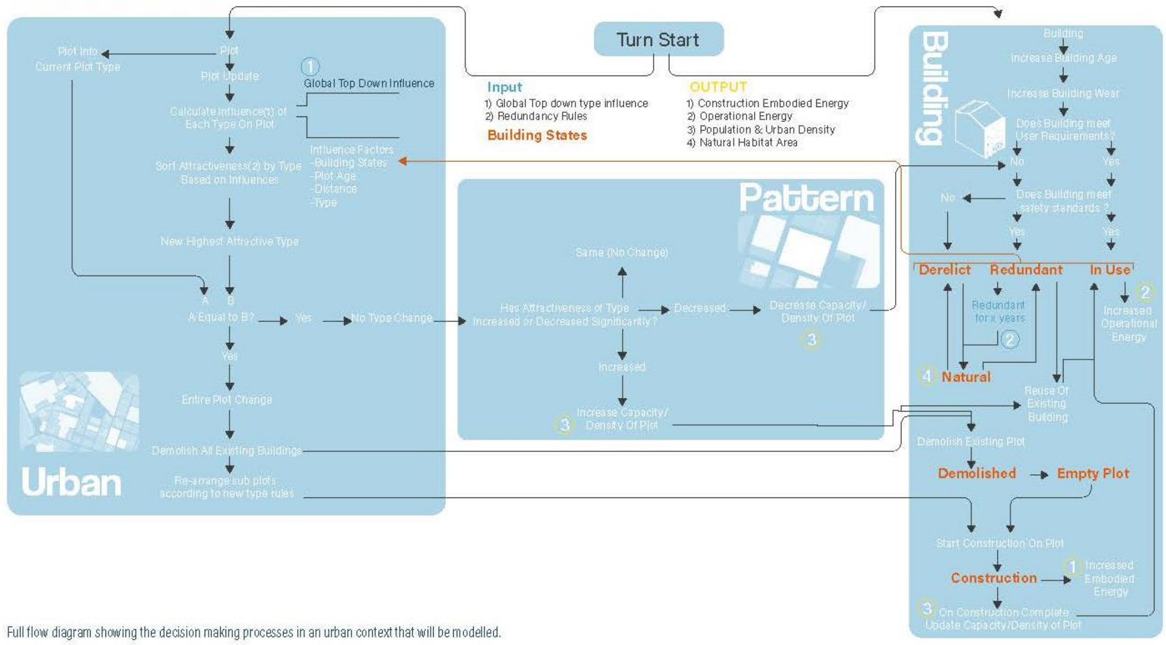
Strategic Urban Phytoremediation: Urban ecologies and patch dynamics



[Figure CH.04: Causal loop diagram for integration of natural ecologies in urban development by Archontia Manolakelli and Mahmud Tantoush.]

The project investigated potential shifts in the future development trajectory of Manchester’s ‘Green Quarter’, a declining light industrial area. The project aimed to challenge the notion that manufactured and human-centric topologies exclude natural ecologies. A causal loop diagram (balancing and reinforcing loops) was used to position phytoremediation – to address soil contamination - as a temporal ecological factor within existing relational dynamics defined by stakeholders. The introduction of this new factor enabled exploration of processes of transformation using a ‘patch dynamics’ framework towards instigating higher levels of urban co-existence with natural ecosystems. The computational approach primarily utilised a cellular automaton approach to simulate the urban system of interest. The simulated design intervention enabled the strategic input of hybrid phytoremediation-based land-use and building types enabling an exploration of dynamically driven alternative scenarios – with readouts on FAR, density and biodiversity potential indicators – over a period of 20 years.

Urban Panarchy: Adaptive cycles for land-use towards reduced energy consumption



Full flow diagram showing the decision making processes in an urban context that will be modelled.

[Figure CH:05: Pseudocode of computational process model enabling the design of interventions within a simulation of urban transformation based on adaptive cycles of land use by Samuel Bland.]

The project aimed to estimate and strategically reduce urban energy consumption at a large urban scale. The urban system of interest (based on the Green Quarter, Manchester) was simulated as a constantly responsive adaptive system using a cellular automata approach. This incorporated multiple scales of interaction based on Panarchy, including cycles of land-use per plot (E.g. unused, construction, redundancy, dereliction, demolition) and probabilities driving interaction between plots (E.g. proximity of residential development to a land fill site). The simulated design intervention incorporated new ecological phases within cycles of plot development to introduce ecological resilience into the balance of anthropogenic and ecological land uses. An Urban Metabolism approach was used to quantify the impact of temporal interventions and cyclic morphological changes in the dynamic simulation for immediate overall embodied and operational energy use readouts.

Design Resolution

The third activity area builds on the knowledge of strategic possibilities for new design interventions within simulated urban systems by formalising potentials for influence compatible with spatial options. The three components involve development of abstract 'spatial strategies' into rule-based computational models, the generation of outcomes or 'spatio-physical organisation' from these models using computational methods and the critical selection of appropriate 'design interventions' or strategies based on their effective value towards achievement of design goals.

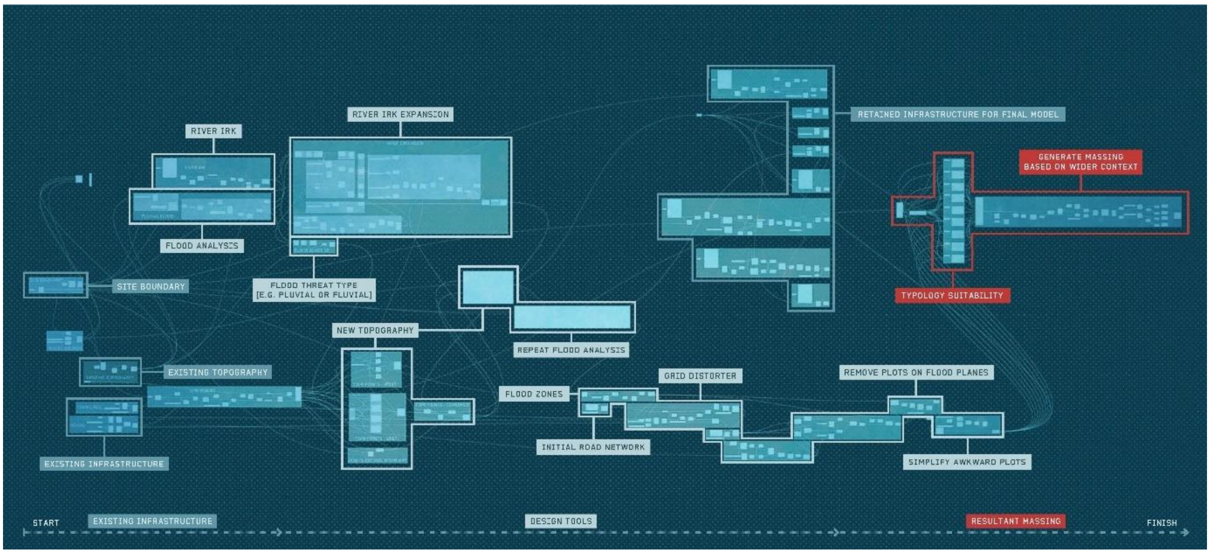
The three areas within the 'design system' apply variations of gamification, AI (data analysis and intelligent agents), automation and virtual reality (visual interaction) to enhance both computer simulation and computer-generated design. However, it is the interaction between the problem formulation, simulation and design resolution areas that provides an understanding of design interventions in their potential to generate alternative futures in the context of complex adaptive urban processes.

Centralising Public Space

[Figure CH:06: Generative design tool to integrate new public spaces into urban patterns by Lowell Clarke.]

The project approaches the problem of sustainability on the basis of neighbourhoods that provide everyday amenities for local residents and hence reduce the need for needless motorised travel. It explores the possibilities of urban development based primarily around access to small-scale public spaces and related local amenities for the benefit of residents. The generative design tool developed in this study enables the assessment of multiple alternative development scenarios based on different spatial distributions and related urban geometries. It utilises an algorithmic process incorporating urban design considerations to generate desirable urban outcomes driven by the inputs for public spaces. The outcomes are assessed in terms of non-motorised accessibility to public spaces, sensitive to street patterns, urban types and the potential dwellings served.

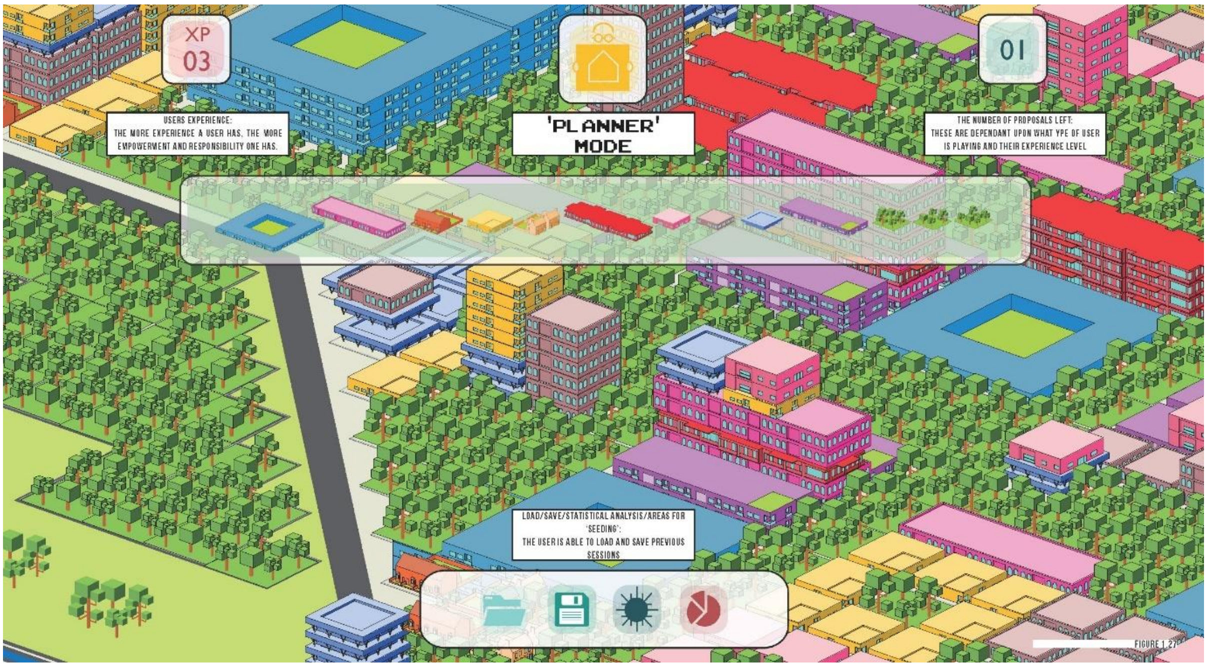
Flood Resilience



[Figure CH.07: Spatial strategy as generative design tool incorporating alternative flood resilience strategy by John Foley.]

The project responded to the statistically rising environmental risk of river flood threats in Manchester, in the context of extreme rain. It undertook is higher resolution analysis than flood risk assessments from government agencies to support spatial design interventions at an urban scale. The generative design tool developed enabled the design of urban areas though an informed manipulation of the topography towards greater flood resilience and control of water run-off. This main driver was part of a process of design-automation where the incorporated rules from known urban development strategies and types was subsequently used to produce alternative future designed scenarios through the initial manipulation of topography for flood resilience.

MakeMyManchester



[Figure CH:08: Web based participatory design tool to create cities based on serious role play game methods by Patrick Lyth and Jordon Lambert.]

The project addressed the difficulties of residents participation in urban change strategies – especially where these concern long-term societal agendas such as environmental sustainability – by developing a web-based participatory game. The web based participatory design tool developed using the Unity game engine utilises custom coding of game mechanics and a representation of actual city features to enable players to operate in various modes such as resident, planner, developer. This gamification approach to understanding the contestations and desires of local populations is complimentary to computational simulation and modelling as it allows first-hand study of dynamics. It is also a way for designers and resident populations to test their own interventions within a multi-stakeholder and objective (complex) system.

Design and Sustainability

Spatio-physical structures generating the conditions that encourage certain human activities is a supplementary area of inquiry into urban environmental sustainability, where the dominant discussion focuses on behaviour change for households in terms of energy consumption and travel activities. Traditional research on behaviour change typically accepts that the environment cannot be adjusted. Architecture and urbanism are in a unique position to engage with sustainable development through reconfiguration of physical arrangements and organisation of space and time in the built environment while integrating the wider considerations of land use-transport integration. The looped influence of spatio-physical structures and behaviour remains a complex problem for sustainable development. By spatialising aspects of social, economic, temporal and technological considerations through abstraction, theory and systemic strategies, it becomes possible to unravel the inherent complexity and contradictions for architecture, urban design and planning processes. The systemic approach enables consideration of both problem formulation and design resolution in terms of relevance and approach across multiple scales ranging from users to policy.

The 'design system' itself is part of evolving methodological research with current emphasis on the identification of 'better' design strategies and outcomes. The process has particular relevance for governance and strategic planning due to the creation of multiple design pathways and outcomes that can be analysed in terms of ambition, effectiveness and practicability. It remains distinct from City Science approaches supporting evidence-based decision making as it generates future scenarios through design approaches that demonstrate avenues to change existing trajectories of urban transformation.

The integration of a complex systems perspective with computational thought experiments is of particular importance when designing for sustainable futures that can be influenced by emerging technologies such as cyber-physical and automated systems. Sustainable development is a multi-dimensional problem that deals with open-ended urban systems involving synergies and contradictions. Generation and examination of alternative systemic scenarios allows identification of different merits in different dimensions. E.g. The trade-offs between human socio-economic activity and environmental impact.

The unravelling of complex urban processes as temporal and adaptive systems, cognition of the role of design and ability to incorporate or respond to disruptive technologies provides designers with an alternative position from which to engage with climate change and sustainable development. The UK and the EU have committed to becoming climate-neutral by 2050, i.e. achieving net-zero greenhouse-gas emissions. The framework developed here situates design contributions for a sustainability transition within systems of emerging technology, economics and social equity.

Looking ahead, it is essential for designers to embrace processes involving computation and AI if they are going to engage with societal issues from a position of knowledge and expertise rather than as passive bystanders. Advance of processes and methods based on additional skills and robust research takes time. In order to address this, practice and academia need to develop a new space – based on mutual agreement to purposefully evolve the future of design - for design and science to exist together.

[1] *Meadows, Donella, Jorgen Randers, and Dennis Meadows. Limit to Growth: The 30-Year Update. Chelsea Green Publishing, 2004.*

[2] *UN General Assembly, Transforming our world: the 2030 Agenda for Sustainable Development, 21 October 2015, A/RES/70/1, available at: https://www.refworld.org/docid/57b6e3e44.html [accessed 8 November 2020]*

[3] *Rittel, Horst W. J., and Melvin M. Webber. "Dilemmas in a General Theory of Planning." Policy Sciences 4, no. 2 (1973): 155-69.*

[4] *Sengupta, Ulysses. "Complexity Science." Chapter. 21 In Defining the Urban: Interdisciplinary and Professional Perspectives, edited by Christopher Doll Deljana Iossifova, Alex Gasparatos, 249-65. London: Routledge, 2017.*

[5] *Epstein, Joshua M. "Why model?." Journal of Artificial Societies and Social Simulation 11.4, 2008.*

[6] *Groat, Linda N., and David Wang. Architectural research methods. John Wiley & Sons, 2013.*

[7] *Iossifova, Deljana. "Architecture and urban design: Leaving behind the notion of the city" Chapter 10 In Defining the Urban: Interdisciplinary and Professional Perspectives, edited by Christopher Doll Deljana Iossifova, Alex Gasparatos, 249-65. London: Routledge, 2017.*