



Expanding depth and meaning within urban design processes through the application of complexity and evolutionary theories.

MIGUEL, M., LAING, R., LEON, M. and BAXTER, S.

2021

Copyright © 2021 The Author(s). Published by Vilnius Gediminas Technical University.

EXPANDING DEPTH AND MEANING WITHIN URBAN DESIGN PROCESSES THROUGH THE APPLICATION OF COMPLEXITY AND EVOLUTIONARY THEORIES

Marta MIGUEL^{1,*}, Richard LAING ², Marianthi LEON ³, Seaton BAXTER⁴

¹*Design School, Temasek Polytechnic, Tampines, Singapore*

^{2,4}*The Scott Sutherland School of Architecture and Built Environment, Centre for Digital Cities and Society, Robert Gordon University, Aberdeen, United Kingdom*

³*Department of Engineering Design and Mathematics, University of the West of England, Bristol, United Kingdom*

Received 22 April 2021; accepted 18 June 2021

Abstract. Previous research has established the value of regarding cities as complex systems, and as systems which will evolve over time. The research reported in this paper concerns the development of an approach to urban design and management which recognises the complexities of change resulting from design-led urban interventions. The research commenced with a study of urban design and urban management processes, and the manner in which they have been studied in an academic context. The system aims to guide the processes of urban design so that it can be implemented within a cyclical process of evaluation and application. The system aids communication across design teams and improves clarity within the design process for the designers themselves. The specific system also aspires to interconnect theory with practice, while supporting designers to be inclusive and holistic. The paper describes a case study where the framework was applied within an academic setting, related to real urban environments in Singapore. It validates the model's ability to guide students through the design process, give depth to their analysis of urban systems and meaning to their designs. Action research was implemented, to reflect the need for a “practice-changing practice” methodology, that supports a greater understanding of the relationship between theory and practice.

Keywords: urban, management, evolution, collaboration, education.

Introduction

The complex and dynamic character of human existence is intertwined with cultural, social and urban change. Human technological innovations, such as in transportation, communication, health and trade, all affect and change the way we live, as well as affecting the environment around us. Embedding the associated complexity and values within education of built environment professionals is challenging, and requires close consideration of how the themes can be regarded both as a context and a vehicle through which designs are formed. For example, Khan et al. (2013) described a “meta framework”, wherein working across disciplines becomes critical, as does transparency as to the basis for and processes underpinning design decisions. Elsewhere, Bina et al. (2016) explored how educating designers to understand the complexity of sustainable urban design requires longitudinal integration, skills development, appreciation of technical skills, aware-

ness of cross-discipline working and the context within which a project may sit (i.e. society, economy, resources and governance).

One can argue that these processes represent a complex evolution which changes the needs and the very being of the people in urban environments (Lefebvre, 1991). Similarly, the implications and effects of urban design shape us as people, the tools we use, our environment and even the way we perceive ourselves and the world we live in (Marshall, 2009).

The study of complexity theory applied in the context of cities emerged when authors including Prigogine and Nicolis (1977) and Haken (1983) became aware of physical-material systems which self-organised and exhibited the phenomena of emergence (Haken et al., 1995). Previously, this phenomenon was related only to organic systems or socio-cultural systems but not material ones. Soon after that, theories of emergence and self-organising

*Corresponding author. E-mail: magm116@gmail.com

systems were applied to a variety of domains in the social sciences and the study of the urban form. The metaphor of the city as a self-organising system was first used by Prigogine and Nicolis (1977) and studied further by Allen, who also related the idea of evolution with the understanding of dynamic complex systems (Allen, 1981, 1997, 2012). The consequence of this was the emergence of a new domain of study of cities which is commonly addressed as complexity theory of cities.

Geddes (1915/1949) was a pioneer in identifying the deeper order of the *natural city*. He was the first to address the city's complexity and to relate it with nature. Instead, he recognised "the order of life in development". Geddes was the first one to argue against traditional town planning and to address planning from an ecological perspective. He argued against the importance of understanding cities and cities evolution before intervening in them (Marshall, 2009, p. 129). Jacobs led traditional urban theory to question its view of cities: Building on Warren Weaver's work, she recognised the problems of the city as problems of organised complexity. Since Jacobs (1961) introduced an alternative way of looking at the urban form and urban dynamics, our understanding of the city as a kaleidoscope of complexity has hardly changed. Complexity sciences see the city as a complex organism evolving and changing according to specific rules and conditions (Bak, 1996). The study of cities today is much closer to biology than to economy or art.

Evolutionary theory can explain the role of design and artificial selection within human and urban evolution and the relationship between human perceptions and human creations in relation to a given context. Darwin (1859, p. 435), addressed evolution as "*descent with modification through natural selection*" (Marshall, 2009, p. 161) and there is nothing in this statement relating it exclusively to biological systems (Simon, 1996). From a theoretical perspective, the idea of evolution is implicit in the understanding of change in any complex system (Allen, 1981). Therefore, it is a useful theoretical tool to fill in some gaps left by complexity sciences. In essence, the evolutionary paradigm to understand the city suggested by Wilson (2011) is similar to the paradigm of the city as an ecosystem suggested by Batty and Marshall (2009), Marshall and Batty (2009). Wilson (2011), Simon (1996), Dawkins (1976) and others argue that it is true that "*cultural and physiological evolution differs from genetic evolution in their details, but once we take the differences into account, we can explain human diversity in the same way as biological diversity*" (Wilson, 2011). This view of humanity in the overall evolutionary context is what Wilson calls the *Evolutionary Paradigm*. The evolutionary paradigm relates human evolution to its environment; the city. It explains human evolution as the evolution of intertwined aspects of human existence which evolve simultaneously and continuously influence one another. In other words, the evolutionary paradigm explains not only the complex and dynamic character of human, cultural, social and urban evolution, but it also embraces the evolution of hu-

man creations. Wilson argues that evolutionary theory can offer the scientific ground to share knowledge across all fields of science. Therefore, it can inform a realistic and genuinely sustainable urban management system able to deal with the complexity of the human condition in this world and achieve a more holistic overview or urban environments interventions.

Against this background of constant evolution, this research aimed to explore how the management of urban and social systems can be designed to recognise, respond to and emerge from the intrinsic complexities in that system. The research concentrated on the development of a person- and community-centred urban management tool, which can respond to the effects of urban interventions, whilst aiming to foster a sustainable future.

The study reported in this paper aimed to explore how complexity and evolution in urban systems can be recognised and acted upon at the design stage. The research utilised a methodological framework centred on an exploratory intervention management systems model (EIMS), which emerged from study of complexity in urban systems, to explore how this connects with notions of evolution and design in urban management. The paper describes the theories underpinning this approach, and presents the results and outcomes from a study undertaken in Singapore, within the context of urban design education.

1. Design processes in an urban context

A design process is characterised by applying reflective practice and descriptive solution finding to address design problems (Cross, 2008; Lawson, 2004). Numerous processes have been developed to describe steps for solution finding (Schon, 1991; Valkenburg & Dorst, 2008; Pahl et al., 2007). These descriptive processes and models typically present sequences of actions where an initial idea is subjected to analysis, evaluation, refinement and development. If there are issues that arise then the application of feedback-loops make the process restart based on the new parameters that impact the design process. It is a deeply heuristic approach; however, no definite solution is apparent at the end of the process. These stages relate to the designer's thinking processes and the process of generating and developing ideas (Boden, 1991). These steps can be divided into five main phases, which are; understanding the definition of the design context and the design problem; defining design goals; exploring possible solutions; evaluating and testing the design solutions; materialising and implementing the final solution.

This process is not linear; it builds continuous feedback loops that generate new information, new concepts and possible new solutions. It is an interactive process of trial and error which evolves organically into a final solution (Cross, 2008). The models to define the design process have emerged from the design field (Schon, 1991; Cross, 2008) as well as from engineering perspectives (Krick, 1969; Pahl et al., 2007) and have been adapted

and applied in the context of the Architecture, Engineering and Construction (AEC) industry.

An adaptation of Paul and Beitz’s model, suggested by Leon and Laing (2020) and illustrated in Figure 1, was used to demonstrate the general framework that characterises the design process, particularly within early design stages. This model was utilised to frame the design process described in the study because it clearly defines a sequence of stages and links working steps with decision-making steps to path the way from an ill-defined design problem to a solution. This framework offers the ground to articulate how EIMS models bring depth to the design thinking process and rearticulate the sequence of the design process.

Defining the design problem is normally the first step in any design thinking process approach. The design problem normally comes in the form of a client’s or a tutor’s project brief, depending on if it is in an industrial or academic context. Design problems define the start of the designer’s creative process to create an object or solution that meets the client’s or tutor’s aims and satisfies specific constraints. Constraints or limitations might be predefined or emerge from the understanding of the design context and/or the design brief.

Design problems are often unclear in terms of goals and constraints (Simon, 1973). They share common traits with “wicked problems” as they are normally not well defined, their outcomes are not clear, they relate to and are defined by an infinite number of variables, they operate in a context of unpredictability and their constraints are unknown (Tong & Sriram, 1992). There is also no defined, objective solution for design briefs and problems (Rittel & Webber, 1973).

After defining the design problem, there is a need to define the complex system that generates it. This implies a collection of information relevant to the understanding of the design’s social, economic and physical context among others. This information is then analysed, evaluated and

used to redefine the focus of study and identify key-related issues that can impact on design solutions. Only when the design problem and the system of analysis are clearly defined can one proceed to brainstorm ideas, define a concept and develop possible solutions (Cross, 2008). From the understanding of the complex system in analysis and the issues and constraints inherent in it, design goals and strategies are defined, which in return will become the ground for design concepts and ideas to emerge.

During the next stage – the generation of ideas – designers synthesise and evaluate their possible solutions for the design problem deriving from the information gathered during the previous steps and the strategies and goals previously defined. The ideation phase is when concepts are formed and positions are taken to address the design problem. During the ideation phase, objectives are defined, constraints are identified and priorities are established. A vision is formed to guide the exploration of the design form, the clean definition of the design program and define basic guidelines of possible aesthetical outcomes. When the concept design is defined and meets the goals and strategies defined initially, the design thinking process comes to an end. The subsequent steps of the design process are focused on how to translate the concept into a reality; they refer to the detailed development and the design’s materialisation and implementation.

Most design process models emphasise the relevance of the initial stages of the design process, especially the conceptualisation phase. The initial steps of the design thinking process are fundamental to establishing a meaningful correlation between the system of analysis or the design context and the meaning, form and relevance of the design solution. The process of collection and analysis of data happens without the support of any framework, and it is up to the designer to define the topics of research, which will then influence the assumptions made about the design’s context and therefore the nature and relevance of the design solutions.

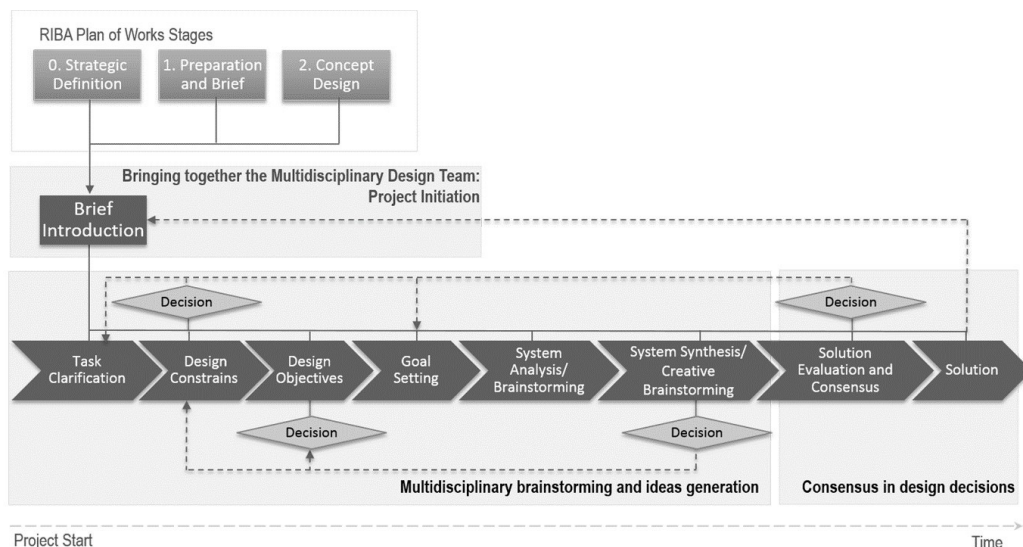


Figure 1. General process for solution finding in Leon and Laing (2020)

The meaningful articulation between the design context and the design solution can only emerge from the understanding of the design context in a holistic way. This requires the analysis of vast and complex information that is not easy to grasp by the human mind in the short timeframes both industry and academia have to respond to. The risk is that relevant areas are neglected and others are prioritised based on the personal choices of the individual analysing the system, and that might have implications on the relevance and adequacy of the design solutions.

2. Study design and methodology

2.1. The EIMS framework

Both the complexity and the evolutionary theory suggested that interventions made in the essential elements from which a complex system emerges can change that system as a whole (Miller, 1978; Allen, 1997; Marshall, 2009; Spencer, 2009). This output supports the hypothesis of using interventions to nudge change in complex systems (Portugali, 2008, 2012). Complexity theory suggests that when we plan an intervention as a finished whole, we consider the urban environment as a predictable system. The interventions we design are, therefore, a result of that image. If the environment changes in ways that we could not predict, the intervention becomes automatically obsolete, or it requires to have the capacity to adapt to new circumstances (Marshall, 2009). In contrast, if we intervene on the elements which comprise the system, the system as a whole transforms with it. In other words, from an emergence perspective, when the components that compose the city change, the shape of the city changes automatically accordingly. Following this, it is arguable that the awareness of the complexity of the urban system and its unpredictability will lead humans to be more cautious when intervening in the city (Loorbach, 2007).

Based on the literature review findings, we developed two models to support professionals such as designers and decision-makers to intervene in the city more adequately. We called these models *The Exploratory Intervention Management Systems* (EIMS), which are comprised out of the basic model and its operational version, or else the framework for supporting the design process. The EIMS models are a pragmatic and straightforward visual representation of complex concepts as emerged from the study of complexity sciences and evolutionary theory applied to the study of cities. The models aimed to improve the design and selection of human actions and contribute in this way to facilitate a more sustainable kind of urban design development. The intention behind the EIMS models was to support designers and decision-makers to reflect on the consequence of their actions and the interrelations between different aspects of complex issues, by making the users feel more responsible for their actions and raise awareness of any unpredictable reactions.

The EIMS model aimed to:

- Help design and decision making professionals to reflect on complex problems and their context from a holistic perspective.

- Relate human actions, namely design with innovation, change and the unpredictability of complex systems.
- Serve as a framework able to relate knowledge and theory with practice.
- Serve as a basis for communication and collaboration across different protagonists in the design and decision-making process.
- Give depth to the design and decision making process and meaning to more responsible human actions.

The EIMS basic model assists its user to envision the holistic nature of complex systems. It defines and takes into consideration key elements to define an urban system and to intervene in it. The proposed model represents a snapshot of the reality of a complex system in a specific time. Its system macro context interpretation involves four key areas, the world views and belief systems, the networks, the environment, the governance and regulatory systems, as illustrated in Figure 2.

The model can be applied to represent human actions concerning a social context. Still, it also enables its users to envision and reflect on the consequences of their efforts over time. In other words, the EIMS model represents a framework to guide the management of change from the perspective of urban design considerations and actions. It contextualises design actions not only with the present reality of a social system but also with its progression in time, thus enabling a historical view of the system's evolution. It aims to be applied as a tool to monitor the emergent reactions of a social network to interventions, and therefore, it allows the user to react to these changes in a consistent manner (that is, in reference to the EIMS itself). The nature of the response and subsequent intervention, of course, will be dynamic and steered by the current context. For the purposes of the study, the framework was

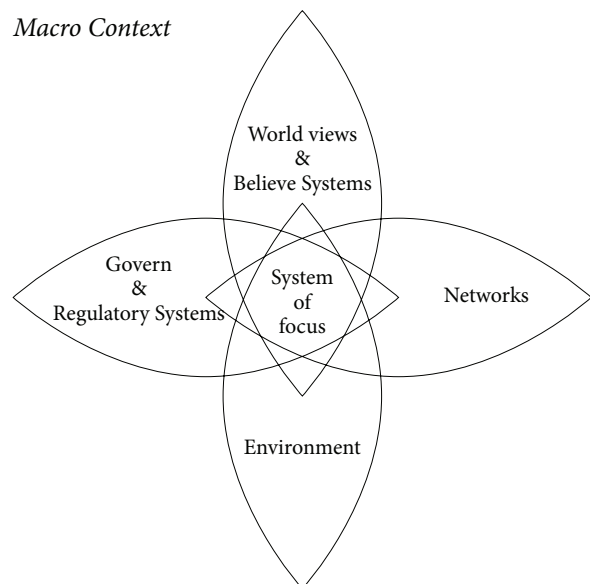


Figure 2. The EIMS basic model

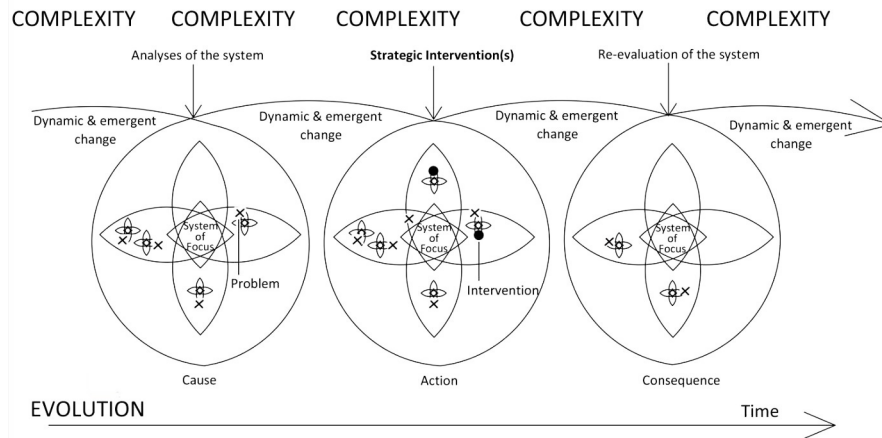


Figure 3. Illustration of the EIMS' continuing responses to dynamic and emergent urban change

translated into a step-by-step process, starting from analysis of the urban system (the cause), to the strategic interventions (the actions) up to the re-evaluation of the urban system (consideration of the consequences), thus creating a framework capable of supporting the design process evolution (Figure 3). The system was also adapting based on the dynamic and emergent change during each step.

2.2. Methodological framework

The study applied a longitudinal and technical action research methods to test, evaluate and verify the EIMS framework; the research approach included repeated measures over time from the same units of observation, to examine the application and impact of EIMS, as a dynamic process over an extensive period of time (Chan, 1998; Ployhart & Vandenberg, 2010; Bollen & Curran, 2006). These measures took place over the course of a full academic year, within Singapore in the School of Design of Temasek Polytechnic, more specifically in the Diploma of Environment Design (EVD).

Action research was implemented since it is a “practice-changing practice” methodology (Kemmis, 2009) that supports a greater understanding of the relationship between theory and practice. Specifically, technical action research was the most suitable approach since its purpose is to promote improvements in terms of effectiveness and efficiency, where the researchers are implementing a series of proposals that would impact the target group (Kemmis, 2014). A longitudinal research design was also utilised and the research followed the same group of students to analyse development within a full academic year (Flick, 2014). The EIMS models were implemented and tested in an academic context to validate the models' ability to guide students through the design process, give depth to their analysis and meaning to their designs; these students were the second year EVD. The study also tested the models' ability to guide users through a self-directed learning process and stimulate people to think in complex systems from a holistic perspective.

3. Study

3.1. Study context

The research was undertaken using the interdisciplinary diploma in Environment Design (EVD), a course which involves a seamless integration of Architecture, Landscape Architecture and Urban Design – three highly demanding, distinct yet complementary disciplines. This means that students not only need to grapple with very complex concepts in each area of study, but they are also required to assimilate their learning holistically.

EVD operates in a real arena, that of a city which requires a deep appreciation and understanding of the habitat that we occupy. The design of urban spaces within the city comprises complex factors that interact and impact each other. Following this, the students are required to tackle both complex sites and demanding briefs; not only the learning outcomes are broad but also the sites allocated to students for study and analysis are multifaceted and require an understanding of various issues and design variables. In this scenario, students need to avoid operating in silos because that could lead to the inability to “connect the dots” or relate interdependently complex concepts across the disciplines. Because of this, the integration of complementary subjects is a huge hurdle, and the challenges facing the EVD teaching team require an innovative approach to teaching and learning.

Due to the nature of the diploma and the need to teach students to decode and analyse urban complex systems and the wicked design problems, the teaching team used the EIMS framework in subjects such as Sustainable Design, Urban Design Studies, and Integrated Design Studio Projects. All three subjects introduced students to a studio-based learning approach of learning-by-doing in a studio environment.

The study focused on a group of 45 second-year students and was conducted over the course of a whole academic year (April 2017 to February 2018). The study was divided into two parts (Figure 4); the first part was developed in the context of the subjects of Sustainable Design

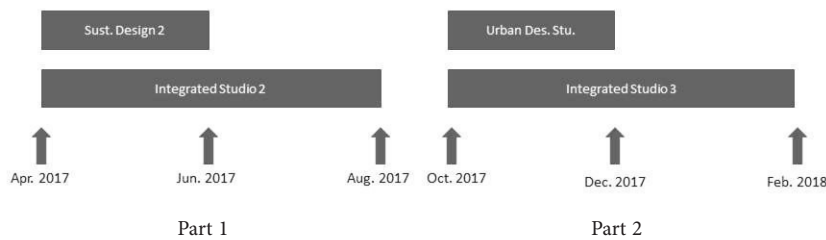


Figure 4. Study parts concerning EVD year 2 students' academic context

and Integrated Studio 2, while the second part was developed in the context of the subjects of Urban Design Studies and Integrated Studio 3. The study observations did not interfere or influence in any way the studio setting during studio sessions, design reviews, consultations or critiques, as per the technical action research methodology (Kemmis, 2009, 2014). As far as the proceedings of the studio sessions are concerned, the intended learning outcomes remained unaltered.

3.2. Study structure

At the beginning of the study, students were introduced to the design process that starts from inception to concept, design development, sketch design, schematic design or design development, detail design and final proposal, as suggested by van Dooren et al. (2014).

For part 1 of the study, the project site was Pulau Ubin, in Singapore (Figure 5). The subject of Sustainable Design aimed to introduce students to the comprehensive site analysis process by applying the EIMS framework. Students were requested to analyse an area and propose design strategies able to address environmental issues with consideration for the community and biodiversity of the site. The learning outcomes of the subject focus on the holistic understanding of a community and guide students to realise the contradictions and wicked problems embedded in the notion of sustainability. Therefore, the subject of Sustainable Design served as a platform to introduce students to the EIMS.



Figure 5. Pulau Ubin – Singapore

For part 2 of the study, the project site was the Duxton Plain Park (Figure 6), which is a complex urban site located at the heart of mainland Singapore. The learning outcomes of the subject of Urban Design Studies are to introduce students to the meaning of social sustainability and sustainable urban development. In this subject, participants apply the EIMS once again to analyse complex urban forms and suggest urban strategies to nudge urban change towards a sustainable future.

Part 2 of the research (Urban Design Studies) served as a consolidation of the EIMS introduced in Part 1 (Sustainable Design). In the context of Urban Design Studies, the EIMS was applied to a larger and more complex urban system and with limited guidance by the tutors. Urban Design Studies served to test the framework's ability to give autonomy to the students and guide them to be more self-directed learners. The submission requirements in this subject were similar to the ones requested in Sustainable Design. Tutors acted as observers and consultants when students requested guidance (Kemmis, 2014). Urban Design Studies' briefs were more open and did not specify in detail the submission requirements.

During Part 2 of the research, students followed the design process stipulated by the subject syllabus but were requested to use the EIMS models to test their ideas and the spaces proposed. Presentations took place according to the different stages of the design process, and students were asked to use the EIMS framework to defend and justify their work. Importantly, for the final presentation, students applied the EIMS framework to articulate their narrative.



Figure 6. Duxton Plain Park – Singapore

3.3. Data collection and measures of observation

In both parts of the study, several complementary methods of data collection were used to compile findings and to identify any possible bias in the data collected; these monitoring methods involved surveys, interviews, assessment criteria and field observations in the studio context. Data triangulation and comparison across different sources of data helped to test and enhance the validity of the findings. Triangulation was achieved not only through the comparison of data collected from various methods but also based on students' assessments by multiple teaching staff, thus achieving removal of any biases.

Surveys were used to supplement the qualitative data gathered through field observations and interviews and to expose any bias in the findings (Wellington, 2015). The surveys were crafted so that students needed to express agreement or disagreement concerning a giving topic and followed with an open question to elaborate on their selected choice. This allowed for relating quantitative with qualitative data and therefore extracting more objective reasoning behind the participants' replies to closed questions. Following Wellington (2015), the surveys started with the most direct and easy questions and built up from there. All surveys were short and question randomly to avoid any perception of pattern. The semi structured interviews were guided by a list of open-ended questions (Walliman, 2006). The exact wording and order of the questions were not determined ahead of time (Merriam, 1998), allowing the interviewer to be flexible and respond to the situation in hand, eventually accommodating for unexpected insides.

Student assessments were an additional method applied to evaluate the progression of the students' work and to examine the applicability of EIMS. At the start of the semester, participants were introduced to the subject brief, which defined the learning outcomes of each subject; the assessment criteria sheets were also launched, which defined specific criteria and standards of achievement in each of the design phases of the project work. The intention of the assessment criteria and design brief was to provide the participants with an overview of their expected learning about the design process. The assessment criteria used in the study were created to assess students' performance in each of EIMS framework steps and specific phases of the design process. In other words, the assessment criteria defined the learning outcomes of each EIMS step, as well as the level of development of the thinking process in each phase of the design process. The assessment criteria ensured the consistency of the students' assessment as well as the objectivity of the data collected in this study. These criteria allowed for both a quantitative and a qualitative evaluation of the students' performance in each phase of the process. Field observations also took place during studio consultations, design reviews and critique sessions. The observations were part of the process of "*learning through exposure to or involvement in day-to-day or routine activities of participants in the research setting*" (Schensul et al., as cited in Hennink et al., 2011, p. 179).

3.4. Implementation

The research aimed to test the model's potential to self-educate users and stimulate them to think in complex systems from a holistic perspective during the design process. It explored the use of the EIMS as a tool to provide depth and consistency to the thinking process developed during a design process and tested in what way it influenced the design object.

The design process phases were translated into the following stages: Site Analysis, Design Brief and Masterplan, Concept Design/Ideation, Sketch Design, Schematic Design, Detail Design and Technical Portfolio and Final Design. The summative assessment was conducted at the end of each phase.

The EIMS was translated into the following 9 steps:

1. Define the **system of analysis/focus** and hypothetical **problems** that need to be addressed.
2. Define **relevant layers** of analysis to understand the system holistically. These layers defined not only aspects of the system but also potential areas to intervene in the system and manipulate its path of change.
3. Analyse the **system by overlapping** the layers of analysis. Participants are invited to look for patterns, inconsistencies or opportunities that might emerge from the intersection of two or more layers.
4. Redefine the **system of focus**: after a holistic analysis of the site, participants should be able to identify the core/source of the problems or issues that are apparent in the system. This can guide to changes in focus.
5. Define a **vision** for the future development of the system of focus. They are also requested to define strategies that address the course problems of the system and improve the system as a whole. Strategies can refer to all different aspects of the system of focus and should themselves work as a system.
6. Define a **design brief**: Participants were required to translate the abstract strategies into a design brief. The design brief should include defined and specific information about the project, such as design concept and specific programs and dimensions. This part of the study aims to understand to what extent a deep understanding of the site influences the students' concept and choices in terms of programs established on the site.
7. Make **prototypes**: Translate abstract strategies suggested to address issues on site and the design brief into prototypes. When it refers to the macro scale, ideas are explored in the form of concepts for masterplans. Concerning a specific site, sketches and models are produced to explore form.
8. **Evaluation**: Participants were required to present their work and address tutors' feedback to select or improve design solution. The process of producing prototypes and testing them is a continuous loop which happens both during formative consultations and in summative presentations.

9. Materialisation: Participants were required to produce technical drawings and the specifications necessary for the building to be conceived in a real scenario. This phase deals with safety, regulations and building technological skills. This phase still needs to respond to all the previous ones but it is more technical.

To guide participants through the design process, a series of submissions and presentations were defined to seal the end of each design phase and assess clear steps of the EIMS, as illustrated in Figure 7.

4. Study results

4.1. Field observations

The students were engaged in all classes and were enthusiastically participating during the activities. The class activities and discussions were particularly meaningful as they confronted the students with new topics and contradicting perspectives which led them to question facts that were for them, until that point, considered as absolute truth. The use of the EIMS to frame the design process led participants to ask more complex questions which, in return, led them to search for more qualitative information about the site. Such information included investigations into cultural values of the different ethnic groups present on the site, historical memories and what defines the character of a place, among others.

Participants used the EIMS framework to manage time and distribute work. The fact that the analysis emerged from the intersection of different layers guided participants to develop a holistic understanding of the place. The information and analysis presented in the site analysis showed the participants' ability to relate and extract meaning from the intersection of different kinds of data and to relate information across different urban scales. Moreover, the participants collected and analysed a large amount of information in a short period of time.

During part 2 of the study, the participants attempted to translate the information they gathered into different layers that were visualised on maps of Singapore. Following this, participants defined three scales of analysis to help synthesise information proved to be very useful when translating their macro level research to the scale of the project site. The macro analysis of the site was developed between 1:50 000 and 1:20 000 scale, the side context was studied between 1:5000 and 1:1000 scale, and the site itself was studied between 1:500 and 1:200. This decision simplified the translation of the information across scales and supported participants to keep an overview of the project site. Participants also used the EIMS framework to divide the work so that there were no repeated layers and therefore created a coherent platform to exchange knowledge and ideas efficiently. These decisions were supported by all 45 participants of the cohort, showing the ability of the framework to support collaboration among large groups of people.

Use of the EIMS appeared to assist respondents in consideration of the intersection of different layers of information, meaning that interesting connections between different aspects of the site began to emerge. For example, the conclusions taken from the intersection of the layers led students to identify key aspects relevant to improve the place, e.g. connectivity through the Green and the park connectors, possible relation with the future waterfront, relation between old and new aspects of Singapore's character and culture. Furthermore, strategies and concepts for the masterplan started to appear, focused on the connectivity and transportation networks.

4.2. User engagement with EIMS

Most participants had no prior experience of the analysis of complex systems. Participants who stated they had previous experience referred to small and defined systems whose complexity is not comparable to the systems analysed in this study (Figure 7). Furthermore, all participants stated that the EIMS helped to analyse the project site (Figures 8 and 9). Most of them replied that it helped them to develop an in-depth investigation into different topics and all of them stated that the methodology helped them to make connections across various topics and therefore develop a more holistic understanding of the place. In addition, several participants referred to the fact that the EIMS helped them to synthesise information, draw clear conclusions from the data gathered and translate these into strategies to improve the system in analysis.

Figure 10 summarises the responses of participants regarding the EIMS contribution during phases 1 and 2 of the design topic.

Most participants felt that the framework was easy to apply, as illustrated in Figure 11. Some noticed that its application required precision of facts; otherwise, inconsistencies emerged when the information was overlapped. Participants acknowledged the fact that the framework

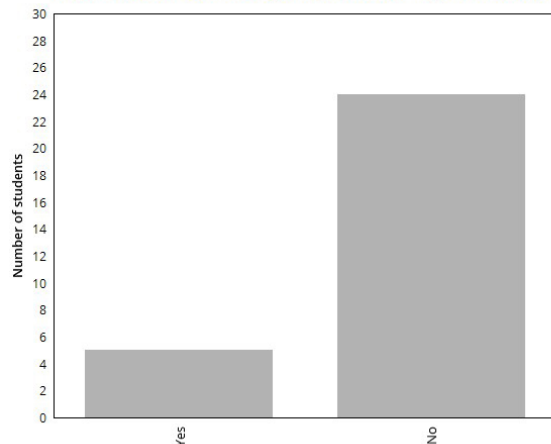


Figure 7. Prior experience investigating a community, town or city

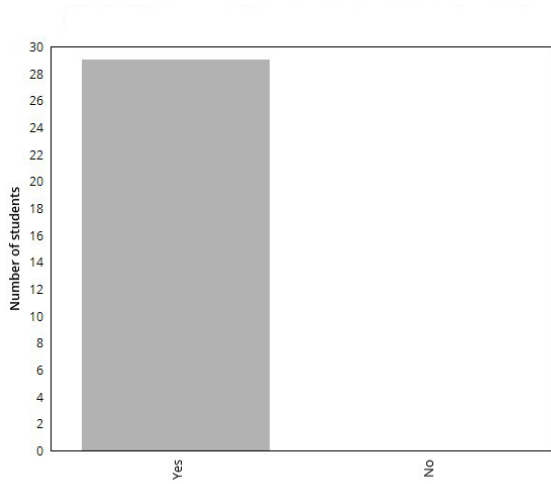


Figure 8. Did the EIMS framework help to analyse the site?

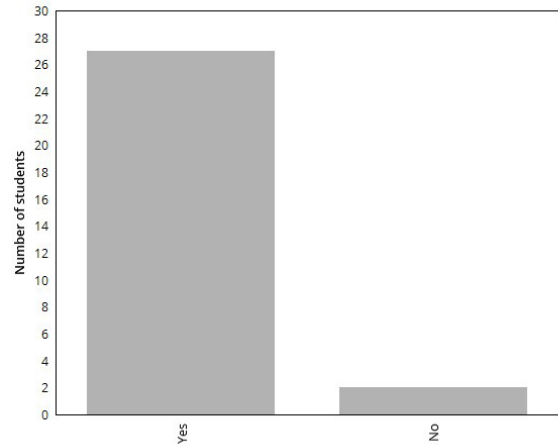


Figure 9. Did the EIMS framework help to undertake in-depth investigation?

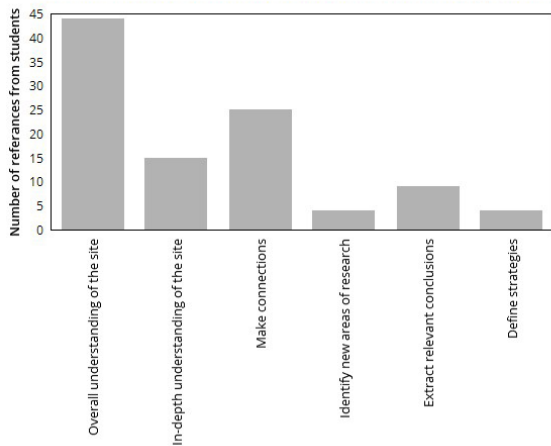


Figure 10. EIMS contribution for Phase 1 of the design process

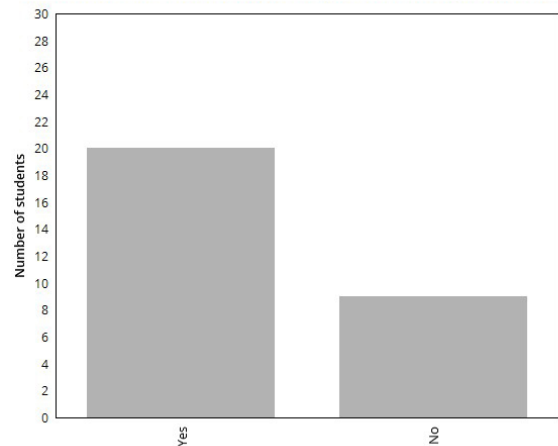


Figure 11. Was the EIMS framework/layer analysis methodology easy to apply?

guided them to think deeper and be more critical about facts. This point is important, especially as the study was conducted in Singapore where people are not used to challenging top-down deliberations – a context where both cultural and political factors offer pressure in terms of freedom of thought and expression. Finally, all participants agreed that the methodology could be applied in other contexts, and they assumed that they would use it in the future.

During part 2 of the study, from a total number of 41 students, 28 responded to a post-design online survey (Figures 12 and 13). From the analysis of the survey responses, we could find that the methodology supported students all through the design process with emphasis on the analysis of the site. From the responses, it was evident that participants based their site research on the layer analysis methodology and that the methodology had a significant impact on the translation of their findings to the design concept, program and form. A more detailed

analysis of the students’ responses was able to identify specific contributions during both the research and the design process.

Participants acknowledged the methodology for supporting them to identify relevant areas of research and make connections between apparently different aspects of the urban system (Figure 14). The methodology guided their thinking process and assisted them in analysing vast amounts of information in a very short period of time. Even if most of the participants refer to the methodology as a tool to study urban systems in a holistic manner, some mentioned its relevance in allowing one to investigate in-depth specific aspects of the system. They mentioned that the methodology helped them to relate information across different urban scales, thereby enabling them to relate their project site with the needs of the overall neighbourhood and even the city (Figure 15). Finally, participants mentioned that they used the methodology to communicate and exchange information within and across groups.

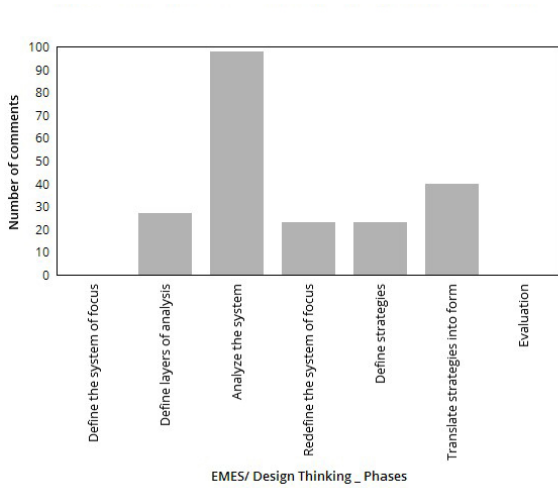


Figure 12. EIMS contribution to support the design thinking methodology

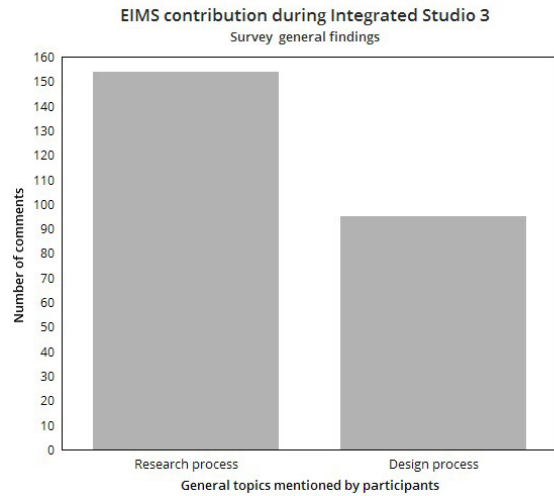


Figure 13. EIMS contribution in relation to the research and design processes

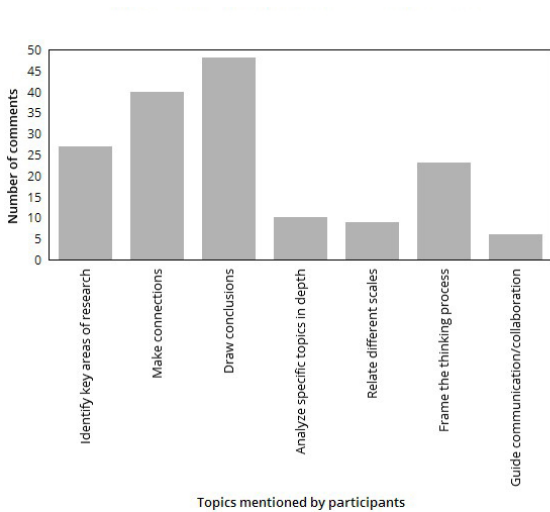


Figure 14. EIMS contribution during the research process

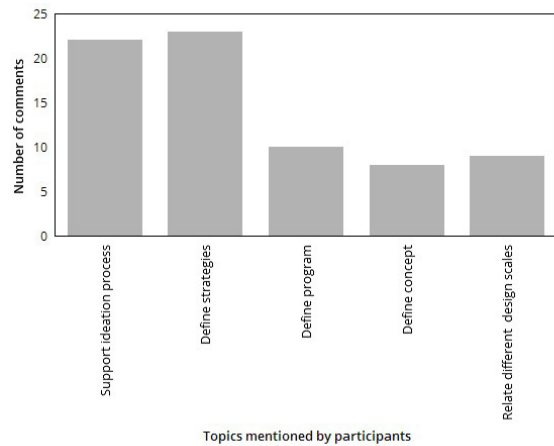


Figure 15. EIMS contribution during the design process

Participants’ highlighted that the methodology was of key importance during the ideation phase, where they had to define how to respond to the site. It enhanced their creativity and the relevance of their proposals. They mentioned that the information analysed was easily translated into strategies to improve the specific urban system which was analysed. These strategies were then translated into specific programs and design concepts. Once more, they mentioned that the methodology helped them to navigate through different urban scales, thereby giving them a more robust ground to support their intentions for the project site.

Discussion

The findings suggest that students’ argumentation during presentations focus greatly on the relationship between the space syntax and its building blocks and the way people use space (Batty & Marshall, 2012). Academic discus-

sions and design proposals in the fields of architecture and urban design were articulated in terms of Alexander’s conceptualisation of components of form: “patterns” (Alexander, 1964, p. 153) and in terms of how the design proposal addresses transitions and change (Loorbach, 2007). Program and form were debated according to the way they interrelate with the elements which compose the system and its nested hierarchy (Alexander, 1964; Miller, 1978; Salingaros, 2000). They were also debated in terms of how they translate human needs (the heart of the system) into spatial solutions (Hodgson, 2011). The findings expressed in this research are in essence, the basis for the development of the design proposals conducted in the study, and they also defined the assessment criteria that generated great part of the data collected.

When comparing the different research methods findings, it becomes apparent that the EIMS framework guides users towards a deeper analysis of complex systems. It allows them to intersect different areas of information and

the understanding of the system across different scales of analysis. From the study, one can conclude that the methodology does not add complexity to the process of site analysis and the design process. It rather adds relevance and meaning to design proposals. As noted by Li et al. (2018), the challenges faced by students learning to understand and respond to urban issues are complex, and require the students to take a holistic view of the subject matter. The EIMS serves to frame those considerations, and in so doing supports the student designers to approach the urban challenge from multiple viewpoints.

The framework can be used to justify architectural forms and programs which emerge from a coherent and in-depth analysis of the system. Users create innovative architectural forms and spaces and used the EIMS to guide their thinking process and add a deeper meaning to the design solutions. EIMS models are more valuable when they are used actively through longer periods of time. After using the framework for one complete round of the design process, participants were able to instinctively apply it again and with very limited supervision. Participants were able to analyse the urban system critically, which in the context of Singapore's traditional education system is a relevant breakthrough. In addition, the EIMS proves to be an effective tool to support communication and cooperation across its users.

Conclusions

This research explored how the uncertainties of evolving and complex urban environments can be made central to the processes of exploring complex urban design and planned management processes in the context of design education. The research suggests that the EIMS could improve the design and decision-making process in two respects. Firstly, they could serve as a platform for communication between the participants involved in the creation, selection and implementation phase of an intervention as well as being used to involve the civil society in the process. They could improve communication and negotiations between experts, managers, designers, decision-makers and private and public institutions involved in the design and selection process of an intervention. Secondly, EIMS could be seen as the basis for a more dynamic kind of decision-making process focused on the design and selection of human actions based on its intrinsic relations with the environment.

The study suggested that EIMS is a pragmatic framework to analyse and intervene in urban complex systems and it can enhance communication and cooperation among its users. The findings also highlight areas worth exploring further in different environments, under different theoretical backgrounds. It also provides a credible and applicable framework which can be used within the formation, education and activity of design teams. The complexity of urban issues is such that the adoption of a multi-faceted and cross-disciplinary viewpoint is essential, including the ability to empathise with the various ac-

tors and stakeholders who may be affected, or who may themselves influence, the eventual outcomes of a design or urban plan. This is further complicated by the continuous evolution of our urban spaces, meaning that "plans" really need to be regarded as targeted interventions, where the eventual implications and effects will require a further cycle of observation, re-design and possibly further intervention. The EIMS provides a structure within which such uncertainties and evolution of the urban space can be addressed.

The EIMS is an applicable methodology to refine thinking and action in the relationship between parts and the complex whole. As it is contextual, its parts change according to the object of analysis, while the methodology stays invariable. The methodology can be easily adapted to the analysis of any complex system regardless of its nature or scale. It can be used to study different urban environments and multiple scales of architectural and infrastructure interventions.

Future research should be undertaken to further test the validity of the EIMS not only within the context of design but in a professional context or in other fields of work that deal with complex systems. There is a need to test the relevance of EIMS to support design thinking in a professional context. The framework should be tested as a tool to guide the design process and support collaboration and communication across all participants involved in it. Further studies should also be conducted to test the relevance of EIMS to support different kinds of users and different thinking processes. Possible applications could be to support the decision-making process and or investigate how the framework would perform in areas such as management, public engagement and sociology and others.

In summary, it was demonstrated that the EIMS can support and guide the design process, and aid designers to recognise and frame their work in a suitably wide context. That is, the EIMS influenced the design concepts without adding complexity to the design process. The models were pragmatic and accessible to young and unexperienced users, bringing depth to their reasoning and guiding them effectively throughout the design process. This finding validates the pragmatic character of the models and this opens the possibilities for broader applications in other fields of work that deal with complex systems. It also opens up the possibility to translate the framework into a digital tool that can be linked with relevant software in the field.

References

- Alexander, C. (1964). *Notes on the synthesis of form*. Harvard University Press.
- Allen, P. M. (1981). The evolutionary paradigm of dissipative structures. In E. Jantch (Ed.), *The evolutionary vision: towards a unifying paradigm of physical, biological and sociocultural evolution* (pp. 25–71). Westview Press.
- Allen, P. M. (1997). *Cities and regions as self-organising systems: models of complexity*. Taylor & Francis.

- Allen, P. M. (2012). Cities: the visible expression of co-evolving complexity. In J. Portugali, H. Meyer, E. Stolk, & E. Tan (Eds.), *Complexity theories of cities have come of age* (pp. 67–127). Springer. https://doi.org/10.1007/978-3-642-24544-2_5
- Bak, P. (1996). *How nature works: the science of self-organized criticality*. Springer. <https://doi.org/10.1007/978-1-4757-5426-1>
- Batty, M., & Marshall, S. (2009). Centenary paper: The evolution of cities: Geddes, Abercrombie and the new physicalism. *Town Planning Review*, 80(6), 551–574. <https://doi.org/10.3828/tpr.2009.12>
- Batty, M., & Marshall, S. (2012). The origins of complexity theory in cities and planning. In J. Portugali, H. Meyer, E. Stolk, & E. Tan (Eds.), *Complexity theories of cities have come of age* (pp. 21–45). Springer. https://doi.org/10.1007/978-3-642-24544-2_3
- Bina, O., Balula, L., Varanda, M., & Fokdal, J. (2016). Urban studies and the challenge of embedding sustainability: A review of international master programmes. *Journal of Cleaner Production*, 137, 330–346. <https://doi.org/10.1016/j.jclepro.2016.07.034>
- Boden, M. (1991). *The creative mind: myths and mechanisms*. Basic Books.
- Bollen, K. A., & Curran, P. J. (2006). *Latent curve models: A structural equation perspective*. John Wiley & Sons. <https://doi.org/10.1002/0471746096>
- Chan, D. (1998). The conceptualisation and analysis of change over time: An integrative approach incorporating longitudinal mean and covariance structures analysis (LMACS) and multiple indicator latent growth modelling (MLGM). *Organizational Research Methods*, 1, 421–483. <https://doi.org/10.1177/109442819814004>
- Cross, N. (2008). *Engineering design methods: strategies for product design* (4th ed.). John Wiley & Sons.
- Darwin, C. R. (1859). *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life*. John Murray. <https://doi.org/10.5962/bhl.title.68064>
- Dawkins, R. (1976). *The selfish gene*. OUP.
- Flick, U. (2014). *An introduction to qualitative research*. Sage.
- Geddes, P. (1915, 1949). *Cities in evolution* (new and rev. ed.). William and Norgate.
- Haken, H. (1983). *Synergetics, advanced topics*. Springer. <https://doi.org/10.1007/978-3-642-88338-5>
- Haken, H., Wunderlin, A., & Yigitbasi, S. (1995). An introduction to cybernetics. *Open Systems & Information Dynamics*, 3(1), 97–130. <https://doi.org/10.1007/BF02228811>
- Hennink, M., Hutter, I., & Bailey, A. (2011). *Qualitative research methods*. Sage.
- Hodgson, A. (2011). *Ready for anything*. Triarchy Press.
- Jacobs, J. (1961). *The death and life of great American cities*. Penguin Books.
- Kemmis, S. (2009). Action research as a practice-based practice. *Educational Action Research*, 17(3), 463–474. <https://doi.org/10.1080/09650790903093284>
- Kemmis, S. (2014). *The action research planner: doing critical participatory action research* (R. McTaggart & R. Nixon, Eds.). Springer. <https://doi.org/10.1007/978-981-4560-67-2>
- Khan, A. Z., Vandevyvere, H., & Allacker, K. (2013). Design for the ecological age: rethinking the role of sustainability in architectural education. *Journal of Architectural Education*, 67(2), 175–185. <https://doi.org/10.1080/10464883.2013.817155>
- Krick, E. (1969). *An introduction to engineering and engineering design*. John Wiley & Sons.
- Lefebvre, H. (1991). *The production of space*. Blackwell.
- Leon, M., & Laing, R. (2020). A concept design stages protocol to support collaborative processes in architecture, engineering and construction projects. *Journal of Engineering, Design and Technology*. <https://doi.org/10.1108/JEDT-10-2020-0399>
- Li, N., Chan, D., Mao, Q., Hsu, K., & Fu, Z. (2018). Urban sustainability education: Challenges and pedagogical experiments. *Habitat International*, 71, 70–80. <https://doi.org/10.1016/j.habitatint.2017.11.012>
- Loorbach, D. (2007). *Transition management: new mode of governance for sustainable development*. International Books.
- Marshall, S. (2009). *Cities design and evolution*. Routledge.
- Marshall, S., & Batty, M. (2009). From Darwinism to planning, through Geddes and back. *Town & Country Planning*, 78, 462–464.
- Merriam, S. B. (1998). *Qualitative research and case study application in education* (Revised and expanded from “Case study research in education”). Jossey-Bass Publishers.
- Miller, J. G. (1978). *Living systems*. McGraw-Hill.
- Pahl, G., Beitz, W., Feldhusen, J., & Grote, K. H. (2007). *Engineering design: a systematic approach* (3rd ed.). Springer. <https://doi.org/10.1007/978-1-84628-319-2>
- Ployhart, R. E., & Vandenberg, R. J. (2010). Longitudinal research: the theory, design, and analysis of change. *Journal of Management*, 36(1), 94–120. <https://doi.org/10.1177/0149206309352110>
- Portugali, J. (2008). Learning from paradoxes about prediction and planning in selforganising cities. *Planning Theory*, 7(3), 248–262. <https://doi.org/10.1177/1473095208094823>
- Portugali, J. (2012). Complexity theories of cities: achievements, criticism and potentials. In J. Portugali, H. Meyer, E. Stolk, & E. Tan (Eds.), *Complexity theories of cities have come to age*. Springer. https://doi.org/10.1007/978-3-642-24544-2_4
- Prigogine, I., & Nicolis, G. (1977). *Self-organization in nonequilibrium systems: from dissipative structures to order through fluctuations*. John Wiley & Sons.
- Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4, 155–169. <https://doi.org/10.1007/BF01405730>
- Salinger, N. A. (2000). The structure of pattern languages. *Architectural Research Quarterly*, 4(2), 149–162. <https://doi.org/10.1017/S1359135500002591>
- Schon, D. (1991). *The reflective practitioner: how professionals think in action*. Ashgate Publishing Limited.
- Simon, H. A. (1973). The structure of ill structured problems. *Artificial Intelligence*, 4(3–4), 181–201. [https://doi.org/10.1016/0004-3702\(73\)90011-8](https://doi.org/10.1016/0004-3702(73)90011-8)
- Simon, H. A. (1996). *The sciences of the artificial*. MIT Press.
- Spencer, D. (2009). Cities and complexity: understanding cities with cellular automata, agent-based models, and fractals. *Journal of Architecture*, 14(3), 446–450. <https://doi.org/10.1080/13602360903028044>
- Tong, C., & Sriram, D. (1992). Chapter 1: Introduction. In C. Tong (Ed.), *Artificial intelligence in engineering design*. Academic Press. <https://doi.org/10.1016/B978-0-12-660562-4.50008-X>
- Valkenburg, R., & Dorst, K. (2008). The reflective practice of design teams. *Design Studies*, 19(3), 249–271. [https://doi.org/10.1016/S0142-694X\(98\)00011-8](https://doi.org/10.1016/S0142-694X(98)00011-8)
- van Dooren, E., Boshuizen, E., van Merriënboer, J., Asselbergs, T., & van Dorst, M. (2014). Making explicit in design education: generic elements in the design process. *International Journal of Technology and Design Education*, 24, 53–71. <https://doi.org/10.1007/s10798-013-9246-8>
- Walliman, N. (2006). *Social research methods*. Sage. <https://doi.org/10.4135/9781849209939>
- Wellington, J. (2015). *Education research: contemporary issues and practical approaches*. Bloomsbury Publishing. <https://doi.org/10.5040/9781474236966>
- Wilson, D. S. (2011). *The neighborhood project*. Little, Brown and Company.