Chapter 1

Axiomatic Design in Regenerative Urban Climate Adaptation

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Abstract This chapter invokes the urban design community to provide transparency in design decision-making by discussing the role of design specifications and the production of evidence in enabling scrutiny and accountability of design proposals in relation to fulfilling sustainability goals and fighting climate change. It claims that original and verifiable regenerative design solutions emerge from clear design specifications supported by evidence, rather than normative sustainability alone. Evidence is understood as going beyond targets and extended to design specifications which are constantly tested in terms of flexibility and robustness, positively contributing to the ecosystem they are inserted in, once further decomposed towards a more detailed design proposal. Principles from Axiomatic Design are proposed as an approach to develop design specifications for regenerative climate adaptive urban design. This work attempts to illustrate the use of this method to practitioners through an example in which human-centric needs, values and aspirations are transformed into joint urban air pollution and outdoor bioclimatic comfort design requirements to be fulfilled by greenery, a regenerative design parameter common to both knowledge domains at the pedestrian layer of the urban environment.

Keywords Regenerative design · Integrated design · Urban climate adaptation · Green infrastructure · Climate-responsive design

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1.1 Problem Definition

Sustainability standards which focus on multi-criteria evaluation systems (such as the Building Research Establishment Environmental Assessment Method – BREEAM, Leadership in Energy and Environmental Design – LEEDS) are being surpassed by more comprehensive certification processes. These new certification processes contain challenging mandatory requirements to be integrated within a design narrative based on solid arguments supported by evidence, such as performance in-use (Living Building Challenge and the WELL Standards). Requests for narratives in supporting accreditation requirements are threefold: First, they acknowledge that only integrated design, rather than a collage of Key Performance Indicators (KPIs) from different knowledge domains, can produce truly regenerative solutions which positively contribute to the ecosystem they are inserted in, restoring the original qualities of the site and context to its original conditions and beyond (Brown, 2016; International Living Future Institute, 2017; Sonetti, Brown, & Naboni, 2019). Second, they set design teams free to use their own expertise and creativity in proposing integrated solutions to incorporate mandatory requirements in an integrated way despite imposing targets that are more rigid. Third, they increase the potential for real innovation to happen in a transferrable format, as narratives can be stored and analysed to extract knowledge.

Whereas this idea is sound and has a true potential to produce radical transformations on the built environment, practitioners still face the question of how to generate robust design narratives, substantiated by evidence so that integrated and restorative design solutions can emerge?

Approaches to integrate different KPIs are traditionally undertaken via Multi-Criteria Decision Analysis (MCDA) (Li et al., 2020; Rodríguez-Espinoza, Aguilera-Benavente, & Gómez-Delgado, 2020), Analytical Hierarchy Processes (AHP) (Aksu & Küçük, 2020; Bivina & Parida, 2019) and optimization routines of different types (Eicker, Weiler, Schumacher, & Braun, 2020; Jia, Li, & Liu, 2020). These methods are highly deterministic as they constrain problem framing to the setting of weighting systems or predefine ranges of acceptable solutions without transparency and real control in the rationale behind different parametric design combinations. There are also some studies in the area of applying ‘Parametric Design methods’ to neighbourhood scale projects (De Luca, 2019; Naboni et al., 2019), interpreting it as a decision-making method whereas it is actually an environmental ‘tool’ developed to undertake sensitivity tests to understand the effects of specific design actions into one or more KPIs rather than a rationale or overarching framework to analyse and control decisions.

What the design community does not realize is that none of these methods addresses the problem in its essence. Designers and consultants use evidence that comes from domain-specific models of reasoning to make decisions. However, domain-specific models are fed by input parameters (physical variables) that are common to different disciplines. These input parameters (physical variables) are optimized in disciplinary silos, to achieve domain-specific performance targets. Decision-making in relation to how physical variables are manipulated needs to be

reconciled among different disciplines as it emerges from different scientific approaches to the problem and/or different ‘social constructions’ of it which are mutually irreducible (Thompson & Beck, 2014). Take for instance the case of a design team in which a landscape designer, who proposes specific types of greenery as a barrier to configure a quiet sitting area, is in conflict with a wind expert, who after some wind tests, proves that the position of this wind barrier actually creates higher wind speeds leading to uncomfortable and/or potentially dangerous spaces to sit. The conflict arises from the fact that each expert has a different goal – ‘provide a quiet sitting area’ and ‘protect from the wind’ – but both propose the use of the same physical variable to achieve it – ‘greenery’. Reconciliation in this case can be lengthy and pursued using trial and error through several experts’ interactions (a time-consuming, costly and therefore unrealistic option), ‘adjusted’ by attributing different weights to expert goals (with the ultimate criteria of prioritizing safety in this case), abandoned and adopted based on the worst-case scenario (follow the wind expert to avoid future liabilities). The likelihood of achieving an integrated solution in this scenario is low because, with the exception of the costly trial-and-error approach, others will favour reconciliation only at the level of the solution, rather than coordinating expert knowledge by examining the pair ‘solution–design parameter’ proposed to achieve it by assessing the implication of manipulating them in subsequent experts’ actions.

The authors hypothesize that since regenerative urban climate adaptation is a multi-domain problem, which traditionally uses evidence from different types of models sharing common input parameters; it needs to be approached from a multi-expert problem framing perspective starting from specifying common, potentially human-centric, goals. These goals should control the development of scenarios used as trials for a series of design specifications from multiple domains with associated design parameters common to many domains, which are constantly tested in terms of flexibility and robustness in relation to all domains involved, once further decomposed towards a more detailed design solution. Principles of Axiomatic Design (Suh, 2001) are proposed as an approach to develop design specifications for regenerative urban climate adaptation.

By specifically focusing on the domains of urban air pollution and outdoor bioclimatic comfort, the authors propose to demonstrate how, in theory, Axiomatic Design can be used to control decisions, which involve the selection and manipulation of greenery, a design parameter common to these two knowledge domains. Centring the problem around providing a physical environment suitable to human well-being, the work initially proposes a list of well-being requirements to be satisfied, followed by combined thresholds of optimum ranges of wind speed, concentration of pollutants and adaptive comfort ranges to be addressed by greenery, a common response to well-being requirements, and at the same time, a shared input parameter between fluid flow and bioclimatic comfort models. This approach shifts the focus of decision-making from a collage of weighted KPIs at the end of the process to the negotiation of acceptable ranges for common design parameters based on overlaid acceptable ranges for targets, which are part of a larger framework with common ultimate goals.

1.2 Current Trends in Urban Climate Adaptation

There is a reasonable number of studies from the perspective of the environmental and physical sciences which focus on quantifying the effects of green infrastructure in urban climate adaptation. Several examples can be found for frameworks and/or tools to determine and map ecosystem service capacity, flow and demand. These initiatives comprised the development of computational tools to be used at regional or urban scale to enable the quantification of green infrastructure in NO₂ removal and outdoor recreation (Baró et al., 2016); the location of green and blue infrastructure to improve storage capacity for flooding mitigation drought and heat stress (Voskamp & Van de Ven, 2015); the assessment of mismatches between ecosystem services supply and demand based on air quality standards and temperature regulation (Baró, Haase, Gómez-Baggethun, & Frantzeskaki, 2015). Several studies can also be found to quantify effects of green infrastructure on mitigating urban heat island effects. At the urban and regional scale, Buchholz, Kossmann, and Roos (2016) compare different adaptation measures based on changing amounts of greenery, water surfaces, surface permeability, reflectivity and conductivity in relation to their impact on air temperature. Makido, Hellman, and Shandas (2019) propose the use of ENVI-Met and Computational Fluid Dynamics (CFD) to examine the use of green infrastructure to change ambient temperature in different land uses. At the neighbourhood scale, Fahmy et al. (2020) use ENVI-Met and Design Builder to assess the effect of greenery (trees, green walls and green roofs) in indoor energy consumption; Vahmani, Jones, and Patricola (2019) couple weather prediction models to urban canopy models to forecast the effect of green roofs in building energy demands in future weather scenarios. Culligan (2019) monitors green roofs to quantify their potential; to retain rainfall, reduce surface temperatures and sequester CO₂. Scharf and Kraus (2019) couple ENVI-Met and GreenPass to assess the effect of different green roof areas in air temperature, Physiological Equivalent Temperature (PET), indoor air temperature, energy flux, thermal load, heat storage, comfort, run-off and CO₂ sequestration. Dunichkin, Poddaeva, and Golokhvast (2019) use CFD and wind tunnel tests to examine the placement of greenery in pedestrian comfort. Despite intentions to provide clear cause and effect relationships, these studies tend to be rather performance oriented detached from human and well-being needs.

Studies on bioclimatic comfort tend to be far more human-centric. There is a significant literature in the area of producing bioclimatic maps through Geographic Information Systems (GIS) to establish relationships between PET and urban density (Cetin, Adiguzel, Gungor, Kaya, & Sancar, 2019); identify optimal areas for comfort around cities (Cetin, Adiguzel, Kaya, & Sahap, 2018) considering meteorological factors and land coverage; assess suitability for tourism considering PET (Daneshvar, Bagherzadeh, & Tavousi, 2013) and Universal Thermal Climate Index (UTCI) (Roshan, Yousefi, & Błażejczyk, 2018); identify relationships between tourist activities and Temperature–Humidity Index (THI) (Ciobotaru, Andronache, Dey, Petralli, et al., 2019); automate the calculation of Heat Index (HI), Humidex (HU) and Wind Chill Temperature (WCT) for any region based on commonly available

meteorological data (Shartova & Konstantinov, 2018). The vast majority of these studies focus on the regional or city scale and are based on identifying or describing relationships between different temperature indices and land use or urban characteristics primarily in hot or moderate seasons. They do not explore cause and effect relationships between different urban parameters and greenery in temperature indices and pollution dispersion. They are difficult to be transferred to the neighbourhood scale as they do not consider microclimate effects in temperature and wind speed as well as how wind speed actually affects thermal perception particularly in cold climates. Authors (Andrade, Alcoforado, & Oliveira, 2011; Dunichkin et al., 2019; Oliveira & Andrade, 2007; Poddaeva, Dunichkin, & Gribach, 2018; Shartova & Konstantinov, 2018) emphasize wind as an important factor in comfortable environments particularly for cold regions. Liu and Kenjeres (2017) propose an integrated CFD and Computational Reaction Dynamics (CRD) model to couple wind speed with pollution dispersion but from a diagnostics perspective, whereas De Luca (2019) focuses on using sensitivity tests as a resource to explore changes in building clustering to modify outdoor wind patterns in the winter to improve the comfort of pedestrians. Dunichkin et al. (2019) discuss the role of greenery to manipulate wind patterns and, based on Dunichkin, Poddaeva, and Churin (2016) and Poddaeva and Dunichkin (2017), the authors propose a framework to discuss wind as a common factor of different environmental models coupled with greenery as a common design solution to manipulate wind to address different well-being goals.

1.3 Methodology

Most designers accept that design proposals come from the generation of a single option, from a repertoire of patterns compiled during long training through experience, from which plausible solution or options are identified by analogy, retrieved and evaluated through mental (or computer-based) simulations (Broadbent, 1988; Goldschmidt, 2001; Schon, 1991 to cite a few). Either when approaching design from this perspective or from a more ‘modern’ perspective undertaken in parametric design environments, in which causal effects of specific design actions are assessed in relation to a series of, primarily formalistic, KPIs (Hudson, 2010; Oxman, 2017; Woodbury, 2010), there is normally a lack of clarity in relation to how, or according to which criteria, plausible options are assessed or evaluated. Design scholars (Lawson, 2005; Schon, 1991, to cite a few) claim this is because the designers tend to assess their design proposals based on what they like better.

[Design] moves are evaluated in terms of how desirable their consequences are in relation to intentions, how desirable the moves are in terms of their conformity to or violation of implications setup by earlier moves and how desirable the moves are in terms the designer’s appreciations of the new problem or potentials they have created. (Bleil de Souza & Tucker, 2015: 60).

Whereas this workflow is flexible and adaptable to the pursuance of integrated design solutions and this is already recognized by standards demanding narratives to explain compliance, it needs clarity in relation to how design specifications are written and can be achieved, so that tight mandatory regenerative targets, from different expert domains, can be fulfilled through integrated/common design parameters. This work elucidates, in theory, that Axiomatic Design is a plausible method to assess design decisions throughout the design process, so multiple domains can interact in factual discussions substantiated by evidence.

Originally developed as a product design method, Axiomatic Design provides a design specification model based on.

[...] principles of functional independence and complexity minimization [in which] problem and solutions are systematically specified in parallel, moving down along the hierarchy and design decisions are made in an explicit way maintaining data. (Marchesi & Matt, 2016: 157).

As displayed in Fig. 1.1, design specifications are built considering customers' needs and aspirations, functional requirements needed to achieve them, design parameters to fulfil these requirements and manufacturing parameters to build the proposed solution (Suh, 2001). Two axioms need to be fulfilled: (i) Functional requirements need to be independent from each other and displayed in a matrix to relate them with design parameters in a controlled format; either diagonally showing full independence (see Fig. 1.1) or triangularly showing their independence can be guaranteed only if design parameters are determined in a proper sequence. (ii) The design content must be kept to a minimum, and the design success with its inherent complexity in terms of information content, is judged in relation to the range of tolerances provided by each design parameter to fulfil required range of tolerances for each functional requirement, as displayed in Fig. 1.1.

1.4 High-Level Requirements and Their Tolerances

Figure 1.1 provides a theoretical framework to be followed when developing specifications for regenerative climate adaptive urban design. Its starts by inviting designers to carefully examine what are people's needs and aspirations in relation to outdoor urban environments. These needs and aspirations need to be translated into functional requirements, that is, the aims that a project needs to fulfil at an abstract level to be successful. Providing comfortable and inviting outdoor spaces that promote well-being through human interaction and interaction with nature can be translated into the following non-exhaustive list of functional requirements (expressed as 'level 1' in Fig. 1.1):

- Provide comfortable spaces to walk
- Provide comfortable spaces to wait/stay
- Provide opportunities to meet other people
- Provide spaces for children to play

Fig. 1.1 The Axiomatic Design approach and its two main axioms

- Provide adults with space for outdoor activities and sports
- Provide spaces to relax and contemplate
- Provide greenery

The aforementioned functional requirements are solution neutral, that is, they do not determine space configurations or shapes to be used in the proposed solution and can be transferred and reused in multiple projects. This promotes clarity and transparency of specification criteria facilitating the dialogue among different disciplines in achieving integrated concrete solutions as experts from different domains will share common design objectives. In addition, it facilitates the catering for these requirements through ideally independent design parameters (as per Fig. 1.1 ‘Axiom 1’). Functional independence is not supposed to be confused with physical independence (Suh, 2001) but guarantees all the needed requirements to be met, producing important benchmarks for quality control.

Regardless of what design parameters are proposed to address these functional requirements, these design parameters have to fulfil another set of environmental requirements related to safety (particularly to extreme climates) and comfort (expressed as 'level 2' in Fig. 1.1). These requirements have prescribed tolerances in relation to human heat balance which need to be met through acceptable outdoor temperature ranges and acceptable ranges for wind speed considering avoiding snow drifts, excessive pressure on the eyes and the concentration of harmful substances in the air. The authors recognize that acceptable noise, humidity, daylight and insolation levels should also be factored in as part of these environmental parameters, but want to illustrate the importance of wind as a key environmental parameter to enable mobility (through avoiding snow drifts and disorientation due to excessive eye pressure), safety (through preventing frostbites) and comfort (through regulating outdoor temperatures), a gap highlighted in the literature review.

Wind speeds are defined based on Dunichkin et al. (2016). They are calculated considering wind gusts and acceptable ranges to reduce concentrations of chemically active dust (rubber, soot and benzopyrene) as well as bio-pollutants (aeroplankton, spores of fungi and mould etc.). Acceptable ranges to avoid eye discomfort and acceptable ranges to prevent snow drifts are also based on Poddaeva, Churin, and Dunichkin (2016), and combined effect on human heat balance is based on the results of solving the heat balance equation limits which is a better indication for cold climates (Shartova & Konstantinov, 2018) as it enables the assessment of 'possible health danger for pedestrians due to frostbite' (De Luca, 2019).

From an overlay of the aforementioned information, acceptable temperatures vary from -15°C to 30°C and acceptable wind speeds vary from 1 m/s (below which there is a high concentration of pollutants and a likelihood to increase the height of snow drifts) to 5 m/s (above which there is discomfort in the eyes). These ranges for functional requirements need to be fulfilled by design parameters with tolerance ranges which are able to meet these requirements. However, the design content must be kept to a minimum, meaning an integrated physical solution needs to fulfil each functional requirement independently. Greenery is proposed as the integrated solution to control wind speed and direction. It contains design parameters which will help coordinating desirable density and permeability in relation to wind in addition to properties which enable the control of daylight, insolation, pollution, temperature and humidity.

Design parameters related to windproof, snow and dust containment properties were extracted from semi-parametric studies of green belts. Several scientific organizations during the Soviet Union (USSR), including the Dokuchaev Scientific Research Institute of Agriculture of the Central Black Land Strip, developed protective forest belts that had windproof properties and contained the transferring of snow and dust. Smalko (1961) and Vinokurova (1953, 1970) assisted in parameterization and introduced new terms on the openwork of forest belts (i.e. definitions for different greenery arrangements with corresponding percentages of permeability for different greenery layers), which were used to develop recommendations for greening cities in the works of Mashinsky and Zalogina (1978), as well as in the work of Chistyakova (1978). Results from these studies were included in terms and

Fig. 1.2 (a) Example of a recommended planting scheme for protective forest belts with trees and shrubs based on the work of Pokrovsky (1991–1996); (b) Typical graph for wind-protective properties of a forest belt with various types of structure based on the work of (Gorokhov, 1991)

definition of the state standard GOST 26462–85 for Agricultural afforestation developed by the USSR Ministry of Agriculture (GOST, 1986) and later listed in the Small Medical Encyclopedia (Pokrovsky, 1991–1996) as useful to regulate the effects of harmful substances and noise.

Figure 1.2a displays an example of forest belt profile showing an arrangement of rows of shrubs (lower layer and upper layer), auxiliary trees and main species (lower layer and upper layer respectively) with a total configuration width of 21 m based on the work of Pokrovsky (1991–1996). Figure 1.2b shows a typical graph for the pattern of change in wind speed behind a protective forest belt depending on the distance from it based on Gorokhov (1991), illustrating the parameterization of wind speed in relation to distance from greenery for a given configuration.

In relation to snow containment, the general rule is ‘snow is eroded from the surface where wind speed increases and deposited where the wind speed decreases’ (Thordarson, 2002: 17). Wind speed affects snow saltation due to shear stress and this contributes to the ejection of snow particles from a surface. Higher wind speeds also promote snow suspension and therefore transport, which depending on the height of travelling can result in sublimation. However, conditions for snow drifting also depend on the properties of snow cover, with recent or loose snow likely to be dispersed at lower speeds compared to hardened snow.

From the aforementioned studies related to the semi-parameterization of wind speed in relation to different green belt configurations, a set of suitable alternatives of greenery can be selected to test their likelihood to respond to specified ranges of functional requirements. Thus, the probability of success of an outdoor space to be safe and comfortable is governed by the intersection of the design range specified to satisfy the aforementioned requirements and the ability of the system to deliver the conditions within the specified range (as expressed in Fig. 1.1 ‘Axiom 2’). Wind tunnel tests or CFD simulations can then be undertaken to examine how successful a design proposal is considering the stochastic nature of wind speed, frequency and direction in a given urban environment.

Section 1.5 illustrates findings from a previous study summarized in Dunichkin, Poddaeva and Golokhvast (2019) which provides an example of this testing to improve the outdoor conditions of a residential development in Moscow. These were undertaken at the Laboratory for Aerodynamic and Aero Acoustic Tests of

Building Structures, Department of Physics and Building Aerodynamics of Moscow State University of Civil Engineering. They recorded wind speed attenuation as well as height reduction of snow drifts for a set of preselected greenery configurations likely to provide acceptable design tolerances to fulfil functional requirements related to mobility, safety and comfort. Full results of this testing can be found in Dunchkin, Poddaeva and Churin (2016).

1.5 Application: A Case Study in a City

Figure 1.3a shows the result of overlaid thresholds for functional requirements in space after wind tunnel tests and CFD simulations for the Varshavskoye Highway development from the case study undertaken by Dunchkin, Poddaeva and Churin (2016) and Dunichkin, Poddaeva and Golokhvast (2019). Coloured areas indicate zones with wind speed of less than 1 m/s for the most frequent wind directions. They offer low risk of frostbite in the winter as average temperatures are around -15°C and average wind speed is 3.2 m/s. However, they are poorly ventilated when the wind blows from east and west (0.45 m/s). When this happens, an accumulation of pollutants and the formation of snowdrifts can occur. Ideally, the wind

Fig. 1.3 (a) Overlaid thresholds for acceptable ranges of wind speed in m/s in the case study; (b) a zoom into an area in which mitigation strategies are proposed based on Dunichkin, Poddaeva and Golokhvast (2019)

speed in these areas should be on average 2.2 m/s and the wind speed outside these areas reduced respecting the 30 min of time restriction for an adult to stay outside at average monthly wind speed and air temperatures as low as -18°C . This figure is based on the recommendation from the Federal Service for Supervision of Consumer Rights Protection and Human Well-Being from the Russian Federation official document (Onishchenko, 2006). The document states that the time limit for staying outside is approximately two times greater than the WCT time recommended by Nelson et al. (2002), due to the use of warmer clothes, hats with face protection from the cold and considering the type of physical activity performed.

From the overlay displayed in Fig. 1.3a, it is possible to determine what kind of greenery should be used and where it should be placed to promote urban climate adaptation of outdoor spaces in this settlement. Zones of excessive wind speed were treated with specific rows of trees and shrubs to direct wind flow and reduce wind speed whereas zones of wind speed above the pollution threshold (i.e. very low wind speed) were treated with greenery to avoid snow drifts and absorb pollutants. The initial selection of greenery is based on parametric guidelines provided by the literature as discussed in Sect. 1.4, as it contains design ranges likely to fulfil functional requirement ranges specified for mobility, safety and comfort. Once positioned in space, another round of wind tunnel tests and CFD simulations are undertaken to verify the effectiveness and ability of the system to deliver the conditions within the specified range, that is, how successful is the strategy in improving outdoor space conditions. Results are provided in quantitative terms (%) and therefore can be easily audited.

Figure 1.3b illustrates the use of greenery as a mitigating strategy to promote climate adaptation to enable a space for children to play. In Fig. 1.3b, zones of excessive wind speed are shown in blue hatch and rows of shrubbery are positioned around the perimeter of sitting areas with 0.5–2 m spacing, followed by a second row of trees with 5–8 m spacing, configurations which proved to reduce wind speed by 14–21%. Greenery is also used at the borders of the playing area within the red hatch zones to reduce the height of snow drifts by 19–27% where they could also, in theory, absorb pollutants. Figure 1.3a also shows the areas around building entrances as potentially problematic due to high wind speed which were reduced by 10–17% through a single row of coniferous trees or ordinary plantings of deciduous trees (spaced by 8–12 m), intercalated with single-row plantings of coniferous shrubs with thick dense crown (spaced by 1–3 m) or dense single-row plantings of deciduous shrubs (spaced by 0.5–2 m). A summary of the full set of urban climate adaptation measures for this settlement can be found in Dunichkin, Poddaeva and Golokhvast (2019).

1.6 Discussion and Conclusion

This chapter illustrated how Axiomatic Design can be an efficient method to develop transparent design specifications for regenerative climate adaptive urban design. It showed that the whole design process can be rationally described and therefore

becomes easier to coordinate, as well as opened to scrutiny by any of the stakeholders involved. It also provided benchmarks for design quality control through the application of axioms 1 and 2. Applications of the first Axiom resulted in the development of high-level functional requirements which are human-centric, non-discipline specific and need to be fulfilled independently. Applications of the second Axiom resulted in design solutions expressed in terms of their probabilities of fulfilling the range of functional requirements they should cater for.

These applications illustrated that a human-centric set of high-level functional requirements can be a powerful coordinator for environmental requirements related to safety and comfort to be listed and overlaid with regard to their acceptable tolerances. These tolerances can then be used as boundaries to set acceptable tolerances for the different design parameters to be proposed. It focused on the role of wind in affecting different environmental requirements and proposed the use of greenery as an integrated mitigating strategy to manipulate wind speed in order to fulfil different functional requirements. The matching 'requirements-solution' was illustrated through an example of previous work which showed that acceptable tolerances for wind speed once matched with semi-parameterized greenery arrangements in relation to acceptable ranges of wind speed attenuations can minimize trial and error to position design solutions in situ.

The matching pair 'problem-solution' is not new and was originally proposed by Alexander, Ishikawa, and Silverstein (1977) using an archetypal language in which recurrent problems are described in an abstract way so they can be recalled and reused several times without yielding the same design solution. By comparing results of this experiment with the archetypes proposed by Alexander, Ishikawa and Silverstein (1977), the authors suggest that future work could be developed around integrating the environmental domain with the social domain. The work in this chapter, for instance, relates in particular to patterns 60, 106, 68, 102, 115 and 121 from Alexander, Ishikawa and Silverstein (1977). The idea of using greenery as an integrated design solution fits with pattern '60 Accessible green', which states greenery needs to be 3 min away from users, so distance does not overwhelm the need. It also fits with pattern '106 Positive outdoor space' which enclosed by greenery responds to specific outdoor functions rather than being a 'left over' between buildings. The positioning and configuration of the playground somehow fit with the pattern '68 Connected play' as greenery is used to configure a more comfortable environment to play, safe from traffic, whereas the treatment of building entrances somehow fits with pattern '102 Entrance transition' as greenery is used to mark a change of feeling, protecting entrance areas from the wind. Notable connections can also be found with pattern '115 Courtyards which live' and '121 Path shape' in which walkability and spaces to wait can be merged, facilitated by outdoor comfortable conditions shielded from the wind. More discussion is needed to integrate the environmental with the sociocultural, but the establishment of human-centric functional requirement as coordinators for environmental requirements and design parameters is a promising start.

To the best of the authors' knowledge, no similar methodological approach was proposed using clear scientific tested examples for coupling wind speed and

greenery, with wind speed being a common environmental parameter to many different types of comfort and pollution models and greenery being a common type of integrated design solution to urban climate adaptation. This being the case, the authors also suggest that future studies can be developed to transform the second Axiom into an assessment process embedded in a parametric software design library to inform designers of potential ‘problem-solution’ matches to minimize trial and error as well as the number of simulations to verify in situ response.

Robust design specifications are an under-explored domain of urban design, perhaps because urban design problems traditionally fall within the umbrella of wicked problems, in which contradictory and changing requirements are to be reconciled. This work attempted to provide better means for design scrutiny, essential not only to organize and reconcile arguments but also to evidence regenerative solutions. Beyond that, it expects to have opened avenues to structure design knowledge in an instrumental way to urban designers facilitating knowledge transfer and management without hindering creativity by remaining open to the use of different concept generation methods but providing a robust test base for solutions which emerge from them, at the same time feeding back on the climate impact on humans in the urban environment.

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