Approach to Design for Resilience to Climate Change

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ABSTRACT **The occurrence of frequent shifts in weather conditions and extreme weather and climate events brings numerous direct and indirect consequences for the built environment, increases the possibility for disaster occurrence, and accordingly sets new challenges for contemporary architecture. The design focus on climate change mitigation, i.e. on sustainable and, above all, energy efficient buildings, therefore needs to be expanded to strengthen the capacity of such buildings to withstand climate change manifestations while remaining functional. To design for optimal climate change-related performance of buildings, now and in the future, a resilience scenario is needed. This work analyses climate change complexity and dynamics as key factors that articulate the design strategy for climate-resilient buildings. Based on the relevance of reviewed risks, variability, and uncertainty regarding climate change, this work maps a generic design framework, explains the meaning of 'transposed regionalism', and discusses the relationship between resilience and the adaptation of buildings in (un)predictable climate futures.**

KEYWORDS climate change impact, risk, hazard, vulnerability and exposure, resilience and adaptation scenario, design response

1 Introduction: Design Responses to Climate vs. Climate Change

The complexity of purposes and the typological characteristics of buildings have grown throughout history, but the need to provide shelter from (varying) external conditions persists as a basic characteristic of any built space. Examples of vernacular structures, design strategies, and traditional lifestyles from around the world allow for the examination of past methods of coping with the climate. In climates with significant temperature variations, the lifestyles characterised by daily migrations within the same structure, seasonal migrations between the structures positioned in different climatic regions, or migrations characterised by using movable structures, were traditionally practised. Drainage systems, steep roofs, elevated structures, and seasonal migrations between neighbouring, but differently designed, structures within the same household represented a traditional response to precipitations and their variations. To provide protection from the heat, the following measures were applied in traditional architecture: optimisation of the settlement form density; optimisation of the building orientation, layout, surface to volume ratio, and other envelope characteristics; selection of building materials with suitable thermal properties; thermal mass balancing; utilisation of solar control elements; introduction of passive cooling by natural ventilation; various landscaping techniques; and others. Rainwater was harvested and stored to secure water supply in dry periods. To protect buildings from the cold weather, traditional builders optimised building orientation and envelope characteristics, choosing adequate (and available) materials, designing adequate layouts, and applying heat accumulation techniques and insulation, including the earth sheltering (Kosanović, 2007; Radivojević, Roter-Blagojević, & Rajčić, 2012).

Modern design and technologies brought independence from external conditions, imposed a strong barrier between the building and the outside (Levin, 2003), and changed the way in which climate was considered in design. After a multitude of developed architectural directions, distinct design experiments, and theoretical work - some of which took a climatic approach (e.g., Olgyay, 1963) - a wider tendency to unite traditional techniques and contemporary technologies into climate responsive design emerged towards the end of the 20th century, together with the recognition of existence of unwanted changes in the patterns of the external environment. From this time, however, registered changes in climate patterns became so significant and frequent that the definition of climate as average weather for a particular region and period, usually taken over 30-year interval (NASA, 2005), may be questioned. In these new conditions, the traditional understanding of climate as a stable input for design has lost its credibility, and the notion of 'climate design' has altered. Concurrently, the consideration of climate features in design is no longer a question of achieving energy efficiency and underlying sustainability, but a basic requirement for securing the operability of buildings in the long term.

In providing a design response to climate change, the designers are challenged with:

- unpredictability as a basic property of the climate change phenomenon;
- more probable occurrence of extreme weather and climate events in regions where these events did not exist before, which brings a shift in possible direct influences on buildings;
- more probable damaging impact of climate change on building structure and functioning;
- increased energy demands, increased needs to secure indoor comfort and to prevent negative health implications, as well as the need to revise and reintegrate the methods of designing and maintaining comfort, because of sustainability-related and climate change mitigation-related demands; and
- various environmental, social, and economic aggravating circumstances emerging from climate change and representing the indirect implications to architectural design.

Current literature and research addressing climate change adaptation introduce a great variety of terms, definitions, concepts, and approaches, predominantly from a narrow scientific standpoint. However, it is widely accepted that the success in responding to climate change primarily refers to the success in acknowledging and acting in accordance with its complexity and dynamics. This work aims to explore the fundamental scientific facts regarding climate change risks, variability, and uncertainty, to discuss their relevance in building design and to unfold an integrative approach to providing a comprehensive design response to climate change by mapping a general resilience scenario and proposing a generic resilience framework.

2 Addressing Climate Change Complexity and Dynamics

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) indicates the widespread impacts on natural and human systems caused by climate changee on all continents. In recent decades, the atmosphere and oceans have warmed, ice sheets and glaciers have lost mass, and sea levels have risen; the amounts of ice and snow have decreased; the global water cycle has been affected; and different extreme weather and climate events have been registered (IPCC, 2014). In the future, the climate will continue to change and affect the Earth's systems, specific to regional scales (Champagne & Aktas, 2016).

Climate change shifts the ways in which people organise their everyday activities and use designed spaces. The expected continuation of climate change, and the changes in intensity and frequency of its manifestations in the future, will increase the time spent indoors (for example, during heat or cold waves) and set new requirements for built space. Given their life expectancy, it is certain that buildings built today will encounter substantial climate change manifestations (de Wilde & Coley, 2012). New design needs to respond to both present and future variability and impacts, including heat and cold waves, windstorms, droughts, fires, floods, sea level rise, and even landslides (Pacheco-Torgal, 2012).

The complexity of climate change should be addressed in design through mitigation and adaptation. Only concurrent actions within these two complementary approaches, encompassing low greenhouse gas emissions, ability to adapt to the detrimental impacts of climate change and climate resilience (United Nations, 2015), can provide success in reducing the impacts on ecological, social, and technical systems over different time-scales (IPCC, 2014). In order to design buildings that successfully adapt to climate change and resist its impacts, now and in the future, it is necessary to analyse climate change-related risks, uncertainty, and variability.

2.1 Addressing Climate Change Risks

The particularities and austerity of the impacts of climate change, and its manifestations, emerge from risk that depends on climate-related hazards, exposure, and vulnerability (Crichton, 1999; IPCC, 2014). Therefore, risk assessment represents a useful staring point in conceptualising the design response to climate change (Gupta & Gregg, 2012). To calculate the risks arising from the impacts of climate change, Roaf, Crichton, and Nicol (2009) presented the following formula:

(possible) Hazard x Vulnerability x Exposure = (possible) Impact.

Exposure refers to the presence (location) in "places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage" (Lavell et al., 2012, p. 32), such as in areas prone to floods or landslides. Vulnerability refers to the predisposition of a building to be affected adversely, i.e. to the susceptibility to damages and malfunctioning, as well as to the vulnerability of its users, due to the impacts of climate change manifestations. "Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Wilson & Piper, 2010). The reduction of vulnerability and exposure, therefore, is unequivocally related to design efforts to achieve resilience in a building influenced by climate change.

While vulnerability and exposure refer to ecological, social, and technical systems impacted by climate change, as well as to the buildings, hazards (weather and climate events) originate from nature. In their interaction with (vulnerable and exposed) ecological, social, and technical systems, hazards trigger impacts that potentially transform into disasters (Kosanović, Hildebrand, Stević, & Fikfak, 2014). These impacts emerge as direct or indirect consequences of one or more hazards that may occur at the same time and thus generate conjugated effects. For example, droughts are the consequence of the absence of precipitations; floods are the consequence of rising sea levels, extreme precipitation, or the rapid melting of snow; landslides and mudslides are triggered by extreme rainfall events; the combination of strong winds and rainfall leads to a storm; fire is more probable when strong winds are coupled with extreme heat and absence of precipitation; etc. Therefore, climate-related hazards, consequences, magnitude of consequences, and probability of consequences determine the significance of risk (Gupta & Gregg, 2012), and inform the design strategy and measures.

In building design, where the boundaries of the field of action commonly overlap with the site boundaries, only some hazards (e.g. extremely high or low temperatures) can be addressed comprehensively, while the domains of urban planning and urban design may provide larger contributions to the reduction of risks from other climate-related hazards (such as flooding). Spatial conditioning, limitation, and inter-dependent relations point towards the need to combat climate change risks by reducing vulnerability and exposure at different levels of the built (social) environment simultaneously. Even if a hazard is not extreme, high levels of vulnerability and exposure will more likely result in the occurrence of disastrous effects (Lavell et al., 2012). Indirectly, hazards can be addressed through some sustainability measures. For example, reducing the greenhouse gas emissions now contributes to future climate change mitigation.

2.2 Addressing Uncertainty and Variability

The Intergovernmental Panel on Climate Change (IPCC, 2014) advises that the benefits from adaptation can be achieved by lowering the existent risks, i.e. by addressing vulnerability and exposure to current climate variability. In Europe, for example, the most common climate and weather-related disasters that occurred in the period from 1998-2008 were floods, storms, extreme temperatures, wildfires, and droughts (Escarameia & Stone, 2013). Major threats that require short-term action include extreme precipitation, extreme summer heat events, exposure to heavy rainfall, and rising sea levels (European Commission, 2013a). While the present climate variability may be described and, therefore, addressed, the challenge arises with the aspiration for present reduction of future risks, especially regarding the probability of occurrence of extreme events that will largely determine building design (Steenbergen, Koster, & Geurts, 2012).

Weather and climate events that have already been experienced at a specific location may not occur again with the same character, intensity, or frequency, or may not occur at all during a building's lifetime (Guan, 2009; Lavell et al., 2012). On the other hand, vulnerability is particularly high in areas that, historically, have not been affected by some weather or climate event, or by their consequential manifestations (Champagne & Aktas, 2016). The uncertainty in future hazard predictions aggravates the process of embedding resilience into building design, and raises doubt about whether the attributed characteristics will be adequate to resist future climate change and its manifestations, which leads to the conclusion that even the risk to future building performance needs to be included in design process. Near-term actions undertaken to manage risks may affect future risks in unplanned ways and alter their perception (Lavell et al., 2012). The impact of current climate change on social, ecological, and technical systems poses additional risk for the future. Even the description of a future, together with the uncertainty surrounding that description, raises new risks (Eiser et al., 2012). The condition of 'deep uncertainty', characterised by the lack of knowledge or the lack of agreement regarding "(1) models that relate key forces that shape the future, (2) probability distributions of key variables and parameters in these models, and/or (3) the volume of alternative outcomes" (Hallegatte, Shah, Lempert, Brown, & Gill, 2012, p. 2) therefore represent the major issue in responding to climate change in building design. Still, risk assessment results, climate change predictions, projections, or scenarios, i.e. climate change models and simulations, represent the pillar support to design. In this regard, the utilisation of 'robust' methodologies for uncertain conditions may guide design decisions aimed at reducing vulnerability. Besides, building character and diverse duration of service life of different building materials and components require consideration of multiple climate change projections regarding both shorter and longer climate periods (Gupta & Gregg, 2012). In addition, researchers are recognising, accenting the need for, and attempting to develop models that, besides incorporating the risks from future events, include anthropogenic climate change, i.e. actions and trends in social and economic spheres (Roaf et al., 2009), as well as the natural and spatial variability. As the way in which building occupants interact with building systems is likely to change with climate conditions, dealing with the human factor should be taken as a significant design concern (de Dear, 2006; de Wilde & Coley, 2012).

2.3 Addressing Territorial Variability of Climate Change

The variability of climate change is twofold; it relates both to the long- and medium trends of changes (like continued increase of the average temperature, modifications in rainfall patterns, or sea level rise) and the 'surprises', i.e. the extreme events (such as storms or floods) that are not expected far in advance. For both types of manifesting variability, the impacts should be considered on regional, local, and micro scales, because of a wide range of influencing factors, from geographical, developmental, and environmental, to social and economic. For illustration, global warming in Europe is happening faster than in other parts of the world (European Commission, 2013b). According to the projections from several different climate models, the average annual temperature in Europe will increase by 1 – 5.5oC over the course of this century. In Serbia, the average annual temperature increase, calculated for the same period, is 2.6oC (Popović, Đurđević, Živković, Jović & Jovanović, 2009), but the capital city of Belgrade, with a projected average annual increase from 1.8oC to as high as 7.5oC in the worst-case scenario (Agencija za zaštitu životne sredine (Environmental Protection Agency), 2009), could, by the end of the 21st century, become significantly warmer than the average temperatures in both Serbia and Europe. The projected temperature increase for Belgrade is not only due to its geographical position, but also the already modified climatic conditions (Kosanović & Fikfak, 2016). At the micro scale, the level of temperature increase will, like in any built area, vary between the different parts due to urban morphology, land cover, and the existence of urban heat island phenomenon (Emmanuel & Krüger, 2012; van der Hoeven & Wandl, 2015), greenery factor, and traffic characteristics (Fikfak, Kosanović, Konjar, Grom & Zbašnik-Senegačnik, 2017), among others. To respond to the changing climate, therefore, climate models, results of risk analyses, regional design approaches, comprehensive analyses of local and micro (site-based) trends, and impact patterns and the interaction of hazard and vulnerability in situ (European Commission, 2013a; Lavell et al., 2012) must concurrently be taken into account. The whole process can be elaborated by applying different methodologies (e.g. Gupta & Gregg, 2012). Changes in regional climate nevertheless demand a shift in the regional design approach, and learning from tradition and experience of both the subject region and the regions characterised by climate trends, patterns, and events that occur, or are predicted to occur, in a concerned area are particularly valuable in reducing vulnerability.

3 Mapping the Resilience Framework

The provision of design response to climate change dynamics, and dealing with climate change risks, uncertainty, and variability, in order to reduce (present and future) impacts, together represent a very complex challenge. On the basis of the facts provided in previous sections of this work, which draw a map to the resilience scenario, it is possible to identify the critical issues in building design methodology and process, and consequently to organise a generic resilience framework that comprises the following design-related component-actions:

- holistic understanding of the character assigned to a place subjected to climate change;
- implementation of regional and 'transposed regionalism' approaches to design;
- concurrent application of resilience and adaptation as two complementary concepts;
- consideration of present and future climate change risks through the application of a 'robust approach';
- optimisation and integration of building design measures for addressing resilience and adaptation with measures that refer to sustainability (Chapter 4 of this book volume);
- optimisation and integration of measures for resilience to climate change at the building level with measures for resilient and sustainable urban planning and design (Volumes 1, 2 and 3 of the book series *Reviews of Sustainability and Resilience of the Built Environment for Education, Research and Design*); and

– integration of technical with ecological, social, and economic resilience (Volume 1 of the book series *Reviews of Sustainability and Resilience of the Built Environment for Education, Research and Design*).

Under the impact of climate change and the possibility of the occurrence of extreme climate and weather events and their consequences, the character of a place is shifting. Besides a series of input data obtained from risk assessment studies and climate change models, the research (preceding design) of local and micro trends, impact patterns, and the interaction of hazards, exposure, and vulnerability, at a specific location, needs to be carried out. The scope of studies on past and traditional design measures, which informs new design at specific location at which certain climate effects are likely to occur in the future, needs to be widened to include the design responses that have been given at places where those climate effects have already manifested. This 'transposed regionalism' approach to design that is responsive to climate change is especially effective in addressing the long- and medium-term impacts.

In the general context of adaptation to climate change, two main terms are commonly used in literature to depict underlying concepts – resilience and adaptation. The main difference between 'resilience concept' and 'adaptation concept' is that the first relates to the ability of a system and its components "to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (Lavell et al., 2012, p. 34), while the latter refers to the "process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (Lavell et al., 2012, p. 36). The natures of resilience and adaptation are therefore complementary; they both address risks and uncertainty, and, according to Nelson (2011), both aim to contribute to the stability of human societies and their physical environments. In new design, however, resilience is more likely to take dominance over adaptation, precisely for reasons of uncertainty.

To reduce the effect of uncertainty regarding future climate change, occurrence of extreme events, and their manifestations and consequences, the 'robust approach' has been developed. Though not having an optimal performance in any specific scenario (Bakker, 2015), a robust solution is intended to perform well under different climate change futures (Dittrich, Wreford, & Moran, 2016), including the worst-case or over-pessimistic scenarios that consider extreme climate change. Such prioritising is in agreement with the goal of climate change-resilient design to employ robust rather than optimal solutions (Bakker, 2015; Lavell et al., 2012). In addition to this safety-margins strategy, the robust approach encompasses the application of no-regret strategies that address incorrect forecasts and enable good performance that is independent of the climate driver, strategies that are flexible and adjustable, as well as strategies that reduce decision-making time horizons, i.e. offer short-term solutions, which, at building level, refer to the design for shortened service life, especially in highly exposed areas (Dittrich at al., 2016; Hallegatte et al., 2012). To this end, Gupta and Gregg (2012, p. 23) pose the question of whether building adaptation should be implemented incrementally, e.g. every 50 years? In the wider context of resilience, that relates not only to the technical-technological response to climate change, but also to the comprehensive social demands of an adaptive society. Glass, Dainty, and Gibb (2008) introduce the terms 'super-resilient buildings' and 'anything-could-happen-anytime attitude', in order to explain how buildings have to accommodate a wide range of changes throughout their service life, and not only those that directly originate from climate change manifestations.

In the resilience framework, and depending on experienced or probable (predicted) threats, the direct response to climate change is embedded in functional, structural, and aesthetic building concepts, site layout and landscaping, envelope design, comfort provision, selection of building materials and components, etc. and, optimally, in sustainability-related decisions. A systems view, on the other hand, allows for the identification of tension between different spatial scales (Lavell et al., 2012) and therefore for meeting the hazards and impacts generated beyond site boundaries. Building location, and the building itself, can be easily affected by a wide range of external hazardous circumstances, due to the following: spread floods; intensified (outspread) urban heat island effect; damages to municipal resource supply and waste management systems; cuts in accessibility to the critical infrastructure and food supply; jeopardised sanitation and hygiene conditions; increased air pollution; erosion and the activation of large-scale landslides and mudslides; changes in land cover; species migrations; occurrence of invasive species; biodiversity loss; and others. All-round resilient architecture, therefore, aims to respond successfully to both hazards directly affecting the site, as well as the hazards arriving from outside the site boundaries. For this reason, the interdependence of projects (da Silva, n.d.) needs to be recognised at different scales, and the measures for resilience to climate change at building level need to be optimised and integrated with the measures for resilient and sustainable urban planning and design.

4 Discussion and Conclusions

After sustainability, the pursuit of resilience adds another dimension to design projects, gives additional challenges to architects, and redefines the complexity of the design process and methodology, by requiring transdisciplinary and a systemic approach, as well as the inclusion of various correlating agents that determine the future behaviour of a building subjected to climate change. The main objective of a design response to climate change is to reduce the risk that this phenomenon carries, i.e. to successfully overcome the problem of multi-scalar uncertainty of climate change. To achieve the recognised goal, a significant amount of input data, atypical to common design practice, should be used.

Although it seems that it is the uncertainty that informs climate change resilient building design, this condition may be eased by the utilisation of climate models and tools. As it is, however, necessary to take a local- and micro-scale design approach, suited to the specific context of a place affected by climate change, it can be concluded that providing an all-round design response is currently possible only for a limited number of locations. Clearly, further development of climate models and tools that will be usable by designers, especially in developing countries, represents a technical necessity with social justification, having regarded that the buildings represent socio-technical systems, i.e. that the technical resilience ultimately rests with social resilience.

The uncertainty about climate change manifestations, in particular extreme events that carry the highest risks for buildings, as well as the insufficient availability of climate models, and the discrepancy in terms of their accuracy regarding future climate change projections, may be recouped in the design process by adopting a robust approach, time-scaling of the overall building design or of its components, and by reviving regional climate design, which, in the context of climate change, can be renamed as 'transposed regionalism'. Climate-related lessons, gained from experiences at distant places, may be successfully transferred to a place where similar climate change manifestations are happening now or are expected in future, especially when it comes to responding to the medium- and long-term trends of changes.

In addition, the provision of a successful design response to climate change, as recognised by the large body of literature, is conditioned by learning and collaboration. To this end, Lavell at al. (2012) note that, if learning was a central pillar of adaptation efforts, robustness would increase over time. Besides necessary knowledge and an holistic understanding of disaster risk, Da Silva (n.d.) acknowledges the importance of collaboration and partnership with other professionals, policy makers, and decision makers, while Hallegatte et al. (2012) stress the need for comprehensive capacity building, for example by establishing local expertise centres. In all cases, climate change changes the common architectural practice and, just like sustainability, brings research closer to design.

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