AUTONOMOUS AND ADAPTIVE CROSS-SCALAR STRUCTURES AND SYSTEMS

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ABSTRACT

Cross-scala design has vital importance for the future development of adaptive and multi-objective design in architecture, by bridging the gap between often inert structures and their ever-evolving and emerging environmental and social contexts. Internal and external stimulus from users and the environment guide, trigger and inform encoded decisions thought the spectrum of scales. The design of seamlessly embedded correlated networks of heterogeneous performative systems enabling: sensing, processing and actuation provides connectivity and redundancy through the ability to accommodate for synchronized and continuous real time reconfiguration and adaptation.
In order to achieve long-term resilience for the global ecology it is vital to develop architectural systems and structures capable of creating and maintaining synchronized relation with an ever-evolving and challenging context, between and across the broad spectrum of scales. This paper presents research in the field of adaptive architecture with particular focus on cross-scalar aspects which can lead to extended and augmented design possibilities, novel materialization processes, and intricate performative behaviors by establishing and enabling effective control over the increased scale range of the design field. This innovative approach could enable a more profound engagement with emerging complex challenges that are otherwise far beyond the reach of design.

To design strategies for some of the most complex problems now and in the future, we first have to look at our starting point as designers. Quickly it becomes obvious that the fundamental perspective and effective design range in the architectural context has not changed much in the past century or so, contrary to the enormous expansion of technical capabilities developed by various fields of science. Could an enhanced and expanded vision, and more importantly the ability to build effective correlations between different scales while taking into the account their specific strengths and potential, provide designers with an expanded design range, helping to reveal a more powerful, effective and meaningful potential for architecture in the future?

The importance of the extended effective design range is critical because it enables design and materialization of heterogeneous, highly differentiated material systems and structures capable of adaptation in time and space scale. Everything that builds our material world, living and nonliving, organic and inorganic, natural and synthetic exists and has the capacity to perform at a broad range of scales. At the same time, everything that we materialize exists on a range that is often far greater than it was ever designed (as we rarely design buildings down to the atomic level).

Throughout history construction was greatly dependent on the use of biological materials. Their multi-scalar structural differentiations are an inheritance of a once-living organism. These materials offer a wide range of properties that are to a certain point clearly beneficial for construction, but at the same time create a limiting threshold. The problem is that reliance on found properties of biological materials (in the case of wood: fiber placement, directionality, reinforcements, anomalies) that fit the precise and multi-objective sets of criteria needed for construction simply cannot be fulfilled, at least not without a hugely inefficient process. Therefore, in order to reduce and substitute this dependency on found qualities the expanded design range is introduced.

In laboratory conditions functional design range is currently possible down to the molecular and atomic scales. This range clearly demonstrates the potential to design and produce heterogeneous structures with embedded properties precisely through
distribution of matter at the molecular scale. However, for the process to be really relevant in its full potential in an architectural context it needs to be much more broadly applicative. Mass nanofactoring can enable production of complex and heterogeneous cross-scalar formations, capable of a wide range of specially and combinatorial actions. These range from self-repair capabilities and structural reconfiguration to variable energy harvesting and customizable geometry and aesthetic qualities.

Non-layer-based molecular precision n-dimensional printers can produce precisely controllable synthetic performative assemblies. Nano-robots can transport ingredients between locations and coordinate chemical assembly of a product, resulting in active networks of nanoscale production lines embedded and designed as an integral part of designed cross-scalar structures. These heterogeneous structures with embedded networks of sensors, processors and actuators can deal with complex dependences and nonlinear relations of time and space scale varying inputs and outputs.

Nanobots can be made to move in any direction along the track. In contrast to previous bipedal motors, the new device has only one leg anchored to a nanoscale track made of a double-stranded DNA backbone. The robot walks by taking tiny steps that involve its leg tethering and untethering to the DNA backbone and the machine is powered by different “fuel” DNA strands that push it along (Muscat et al. 2011).

Primary focus concentrates on two extreme spatial scale perspectives: super small and extremely large. Both are ever present, yet often difficult to control due to their relation-based specifics and need for the development of specific tools and methods. Subsequently they are often overlooked, despite the vital role they play. Rather than focusing on direct design and materialization of a visible and inhabitable “architectural scale proposal,” the research starts at the extremes where the direct design
intervention is still possible. The resulting cross section forms an enhanced architectural condition, capable of passive synchronized modification, reconfiguration, transformation and adaptation. This combination is comprised of a strategy that is neither introverted nor fixed, but is able to function in the existing scenario and, more importantly, possesses the ability to adapt or transform when the need arises, enhancing its overall resilience. The adaptable ecology that forms the expanded architectural “vocabulary” therefore becomes both a performative generator and an interface that enables communication and coordination that directs the process across the scale stack in relation to the emerging conditions of both hosting and hosted context.

Design focus is shifted from form finding resulting in a fixed geometry with specific performance, to spectrums of controllable transitions, resulting in adaptable morphology. Embedded intelligence enables structures and systems to act as sensing, processing and actuating adaptable units and networks according to need and contextual physical laws and mechanics.

Embedded designed thresholds act as preprogrammed boundaries and switches for material differentiations, structural and aesthetic performance. Heterogeneous composites with embedded potential for variable material performance and variable geometry configurations enable a preprogrammed performative spectrum of actions and behaviors. The design decisions are contrary to the established approach; therefore, they are not always directly visible but exist as a potential that can be activated should the need for them evolve. This autonomous, passively operated orchestration could be especially productive in extreme space and time scales and contexts.

The ability to integrate change as a productive rather than disruptive or destructive factor needs to be present from the initial
design phase. Throughout the construction or assembly, desired functional life, as well as during complete transformation or dis-assembly reassembly, the system maintains the necessary potential for reconfigurability. This process will enable a radical shift—structures would autonomously deploy or activate when certain criteria of the internal or external conditions are met. The process can be passively triggered by detecting and following chemical or physical gradients such as temperature, light, magnetic field, gravity, presence of oxygen, nutrition and so on. This approach plays a crucial role by enabling an entire spectrum of new applications through external and internal direct and real time passive synchronization processes, ranging from relative positioning systems and functional augmentation to intricate deployment sequences.

Distributed embedded control enables autonomous adaptability and programmable responses throughout the broad effective range of external and internal sets of factors. Several examples are:

1. Local geometry change based on a local external condition change;
2. Global geometry change based on a local external condition change;
3. Local geometry change based on a global external condition change;
4. Complete adaptation—transformation of global geometry change based on global external condition change;
5. Local (limited) geometry change based on a local internal condition change;
6. Global geometry change based on a local internal condition change;

“For growth to be so uniform and constant in all the parts as to keep the whole shape unchanged would indeed be an unlikely and an unusual circumstance. Rates vary, proportions change, and the whole configuration alters accordingly” (Thompson 1945: 45)
7. Local geometry change based on a global internal condition change;

8. Complete adaptation—transformation of global geometry change based on global internal condition change.

Governance of structural and performative priorities becomes a major design aspect for real-time synchronization with changes of contextual or user-defined conditions. A radical shift is made to avoid the design phase of finite and superficial, ideal form finding and substitute it with a systematic, constantly updating process where form making and its material transformation is a continuous, ongoing process throughout the life of the system. This governance system becomes the focus of design while its physical manifestations become tangible perceptible symptoms of internal and external interactions.

Heterogeneous, responsive, adaptive and cross-scale interconnected structures and systems can provide the vital resilience in ever-emerging, (un)predictable scenarios. Disconnected and non-contextual object-based design is expanded, transitioning to a process that actively incorporates context as an evolving, fluctuating “sea” of relations between systems and structures, broadening the possibilities in an ever self-negotiating host condition. The focus is shifted from direct and finalized design solutions that are often outdated before they are even materialized to open, evolving, complex relations between different spatial and time scales of both systems and structures. At the same time, arrays of both are becoming embedded one in the other. The resulting dynamics can be described as coordinated intrinsic instability. Instability provides the capability for increased responsiveness and reconfiguration of a system while it is at the same time acting as a driving force throughout its lifecycle.
When the direct or finite design application is not sufficient (often due to very small or very large time/space scales), it can be substituted with the adaptable cross-scalar orchestration through embedded intelligence, processing power and communication through the distributed hybrid structural/performative network.

Since constant and direct input is often not possible due to the emerging complexity and specifics that are forming the design field, an alternative approach is established. It is a more indirect, yet at the same time profound and potentially stronger approach: structural orchestration.

Individual components and building unit scan form heterogeneous performative structures and larger systems based on their local adaptations of material properties, and the geometry establishing relations with other components within and outside of the system. These processes enable construction of diverse and adaptable assemblies of complex heterogeneous structures and networks with redundancy. The ability to form complex heterogeneous structures from the simplest possible adaptable building blocks creates the potential for a rich spectrum of structural and other functional differentiations. This ability translates into a controllable morphology for performance or other specific adaptation. The right morphology in combination with the right materials does not only significantly simplify control but also enables the formation of evolving performative systems.

A transition is made from design of a fixed immobilized architectural condition striving to maintain its static structure toward one capable of adaptation through cross-scalar repositioning, reorientation and reconfiguration. Design of inherently dynamic structural systems can achieve a great degree of resilience through the ability for real-time, contextually synchronized adaptation.

9 Structural differentiations in composition of homogenous building units can form a wide range of reconfigurable heterogeneous structures

10 Geometrical change of the molecular building unit affects formation, stability and collapse of the structure. Microtubules, structure function and dynamics
Structurally and functionally articulated assembly: adaptation, reconfiguration and self-repair.

Synthesis of nano-sized compasses to navigate using Earth’s geomagnetic field.

Oxic-Anoxic Transition Zone (OATZ)

Earth’s Geomagnetic Field in Northern Hemisphere

O₂ concentration

Counter Clockwise

Northern Hemisphere

Clockwise

Southern Hemisphere

Earth’s Geomagnetic Field in Southern Hemisphere

S⁰ concentration

Counter Clockwise
In order to understand, simulate and design with and for potentially changing or renegotiating conditions, ge/o(eco)logical computation enables the definition, design, procedural automation and establishment of internal and external relations, combinations and transitions by taking into account their specifics and potential throughout the space and time scale.

This novel concept relies on a complex system of internal and external relations. It is introduced to overcome the long-established problem and norm of either designing for an isolated, narrow, specific function or the necessity of using found complex assemblies. Instead it opens possibilities to synthesize, combine and embed, unlocking design potential.

The extended effective design range together with the utilization of embedded intrinsic instability will help us materialize buildings and other structures that are not only lighter, stronger and more resilient but also adaptable according to external conditions and customizable to satisfy internal needs.

Ge/o(eco)logical computation establishes a foundation for a real-time, adaptable and relational system of cross-scale structure and performance governance. The structural governance design is of critical importance for this adaptable design strategy. It not only determines the relational logic and combinatory effect of certain specific inputs and effects, but continuously (re)assesses and (re)establishes relations and priority. This approach unlocks the ability to orchestrate a complex series of renegotiating relations, systematic adaptations, reconfigurations and transformations by synchronized positioning, orientation, alignment and selection throughout the space/time scale.

Actively shifting boundaries and conditions forming instability and uncertainty are ubiquitously present. Perhaps the most distinct and familiar example in physical space is the condition of a shoreline; a continuously shifting connection and division of two distinctly different systems: the anthropocentrically dominated solid ground and ever-fluctuating aquatic system. It is clear that throughout history this potentially hostile yet highly active and rich zone often marked the site of intense urban formations. Today, perhaps even more noticeably than in the past, these dense urban formations are subjected to extreme pressures by population density influx, pollution, high ground water levels, water intrusion and flooding. Often the resulting temporary solutions rely on brutal methods that try to physically stabilize the intrinsically unstable.

Would it not be better to harvest and orchestrate the immense energy flow and work with the specifics of this unstable ground, to expand the perception of from a harsh and alien boundary to a rather unique self-renegotiating plane of active and passive interaction? Rather than fighting the immensely powerful environment by brutal force, would it not be better to design a strategy that could work with it, harvest and return, and at same time use its immense capacity to construct, reconfigure and perform?

The process forms a transition and expansion from disconnected and non-contextual design, to a series of processes that incorporate the context not as a passive state, but as an evolving and fluctuating “sea” of relations between systems and structures. The coordinated intrinsic instability of emerging contextual relations and conditions provides the potential for increased responsiveness and reconfiguration of systems and structures while at the same time acting as an energy source throughout its lifecycle. The expanded effective design range and ge/o(eco)logical design computation unlocks the ability to orchestrate complex series of renegotiating relations and structural systematic adaptations, reconfigurations and transformations throughout the space/time scale. This enhanced vocabulary of inclusive, strategic possibilities enables vital future developments by updating and enhancing the domain of architecture and redefining its expanded role for the future.

WORKS CITED


Thompson, D’Arcy. 1945. On Growth and Form.

MAJ PLEMENITAS is an experimental Architectural design practitioner, researcher and academic. His current interest and research is focused on cross-scalar design through combinations of design computational methods. After graduating as a Master of Architecture from the UCL Bartlett School of Architecture, with a multi-award winning thesis 10^9[LINK][10], he established the research platform and design practice LINKSCALE. He is actively teaching at University College London, The Bartlett School of Architecture and continuously researching, exhibiting his work and lecturing internationally.