Extended modelling

Dynamic approaches applied to design reef habitats at Sydney Harbour

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This paper outlines a critical approach to computation in architecture by using multi-agent systems and dynamic simulation tools. Such methods reinforce viewing design as a data-driven process, whereby a problem is analysed to a set of agents and their properties. The related actions assume extensive modelling techniques, recursive experimentation and testing to assist design since the early stages until completion. In reflection, similar methods are employed to tackle problems of content other than architecture. The experiment being discussed is Bio-shelters. It involves designing artificial coral reefs to be placed at the Sydney Harbour, aiming to improve the living conditions of seashell and other endangered organisms. This paper first describes reefs as highly sophisticated ecosystems; then, it proposes methods for designing and constructing ones, further commenting onto their shape, fabrication, materiality and on-site placement, consequently reinforcing that extensive modelling techniques currently applicable in architecture may also respond to different scenarios about our settlements and the environment.

Keywords: Dynamic simulation, data-driven design, multi-agent systems, computational tools

INTRODUCTION
With the advancement of digital tools approximating behaviours, phenomena and influences, it is currently possible to apply an all-encompassing approach about architectural design seen as a performative process (Hensel and Menges, 2007). Extensive data inputs and recursive processes are main applications of computation supporting form-finding techniques. As such, computation may assist in managing a set of agents acting as self-organizing principles during morphogenesis (Weiss, 1999; Weinstock, 2004). Advanced parametric tools have been used to break down a problem to multiple agents described by their properties in preparation for interactions. The related operations assume producing models that are suitable for testing ideas since the early steps until final resolution.

This paper draws upon critical applications of computation in architecture, whereby design is approached as a data-driven problem, first analysed
agents and their properties, then interacting via dynamic simulation to produce various schemes. The appointed techniques assume advanced modelling techniques based on recursive experimentation and testing leading towards increasingly sophisticated outputs. A case study experiment has been developed to test the efficacy of such methods in responding to problems of content other than architecture. The task particularly involves the analysis and further designing of artificial coral reefs to be placed at the Sydney Harbour, an area of rich biodiversity that is also heavily populated. Ideally, the proposed schemes would be informed by reefs’ remarkable complexity and sophistication invested onto their shape, structure, behaviour, materiality, fabrication and on-site adaptation. In assessing the results, it is suggested that extended modelling techniques making use of advanced computation such as those currently applied in architectural design research are suitable to tackle problems about our broader environment, artificial and natural alike.

A NEW POTENTIAL FOR EXTENDED MODELLING VIA MULTI-AGENT SYSTEMS

Multi-agent approaches have been employed in architecture in order to explore the influences of different contextual factors. Initially developed in the 1960s with reference to Cybernetics (Pask, 1969), the underpinning idea has been that a design problem may be described by a set of influences interacting with each other as part of a dynamic system. Same as in nature, elements of an artificial setting may not be seen in isolation, but rather as integrated components of the broader environment in which they belong. Agents pursue goals or carry out tasks in order to meet design objectives, which may be supplementary as well as conflicting to each other. In effect, multi-agent systems have helped to understand, manage, and use distributed, large-scale, dynamic, open, and heterogeneous computing and information systems (Weiss, 1999) rendering those systems more resilient, robust and reliable in relating and managing variable inputs and their influences to proposed schemes. The tentative list of agents in architectural design includes the sum of contextual factors as traits making the architectural system (Ballantyne, Kawiti, Schnabel, 2016). These may be about the site, proximities and surroundings, energy flows, movement, connections and traffic with entry points, regulations, restrictions, enduring and changing conditions, social behaviours, economy and culture, existing and proposed activities, functions and the program. The agents are introduced via a set of data, properties and rules, along with their intensity of impact. They express behaviours, characteristics and properties, as ways to outline potential relationships manifested in the result. Design is viewed as a problem of complex relationships between agents; moreover there is direct connection between the inputs and the form that occurs from the related actions and vice versa.

Relating agents via a system offers alternative ways to describe data patterns, iterative processing and progressive assessment as opposed to aesthetic-driven operations mostly relying on intuition, talent, or subjective judgement. Advanced computation combined with systemic views on architecture makes a synergy in resolving design. With software currently available, data inputs may interact with each other by controlled operations even in real-time. In effect, multi-agent approaches assist to describe a design problem in analogy with science and engineering; then, the outlined functions are interpreted, processed and adapted to answer the problem via digital methods of high accuracy and control. Considering the breadth of applications in engineering, multi-agent approaches such as those described above may be applied to resolve a wide range of scenarios. For this case, advanced computational methods are employed to tackle problems of environmental concern. Specifically, data from marine biology inform prototype models for artificial reefs. It is aimed that the outputs meet the needs of specific organisms as they are also conditioned by the data taken from different environments.
Early schemes may be produced directly as the agents are introduced in a design platform to interact with each other. In architecture, these operations are typically manifested in the context of drawing. The architectural drawing may not be limited to provide technical information or to document design. The drawing is a transitory element, offering modes of systemic association of the data it depicts in a mode being varyingly diagrammatic (Allen, 2000). It shows information about the design factors altogether as topographical data (Vidler, 2010). It further aims to initiate dialogue among all agents and their interaction as in a real-time experiment, as opposed to being strictly a visual statement about the design outcome (Frazer, 1995). Such an operative conception of the drawing is reinforced by generative functions related to the computer seen as an iterative also relational device (Rahim, 2009; Schumacher, 2009). The use of advanced computation to calculate and to visualize the results of interactions has invoked re-addressing the significance of the drawing as an experimental tool where design is performed, rather than one driven by aesthetic operations (Zavoleas, 2014 and 2015). Being supported by the digital, the drawing has been updated to a dynamic simulation model constructed to relate the various agents of design.

The simulation model has operational analogies with scientific ones commonly described as experiments set to reach greater validity. The model in its extended form becomes an active element. Evidently, the main difference between current computational approaches and former ones executed exclusively at the drawing board may be addressed in the tools appointed for modelling and processing the problem. These have departed from the analogue framing with its character and functions often being intuitive to embrace the capabilities of dynamic simulation and real-time interactions, as those performed in experimental settings and contemporary design packages. In the simulation model, multiple agents interact as they are being related to spatial and formal effects. The model - or the drawing in its updated form as a means to visualise agents and interactions - is the collective scene where agents perform together and the technical basis to frame a design proposition.

**EXTENDED MODELLING APPLIED ON ARTIFICIAL CORAL REEFS**

This paper proposes that advanced computational methods employed in architecture as dynamic techniques to produce schemes are equally capable of responding to design problems of other areas (Spuybroek, 2009). The project being presented is Bio-shelters: Design Reef Habitats at the Sydney Harbour, an interdisciplinary research study between architecture, computational design and natural sciences. It has used a multi-agent approach with data from marine biology and bio-engineering to model prototypes for coral reef structures. It is aimed that the produced outputs are designed to meet the needs of specific sea organisms and to offer variations that are suitable to different topographical and environmental conditions. For this purpose, negotiating with existing natural settings has been a critical factor in shaping design schemes.

**The project and its motivation**

Designing habitats for non-humans is proposed as a way to test extended modelling techniques applicable in sensitive natural environments. Artificial coral reef colonies are aimed for locations of diverse marine ecology such as coastlines being under potential threat, since there is also where rapid urbanisation occurs. Evidence for this was given in an article published recently in The Ecological Society of America Journal stating that “some estuaries in Australia, the United States and Europe have had more than 50% of their natural coastline modified with artificial structures” (Dafforn et al., 2015). In the same article, the researchers argue for a “conceptual framework for designing artificial structures with multiple functions,” pointing towards that at present “while the design of artificial structures remains linked solely to engineering goals, their multifunctional potential may not be fulfilled.” The present paper aligns with the
prospect of a ‘multifunctional potential’ by a data-driven design output that can cater for all involved participants. Consequently, designing reef habitats for oysters, barnacle, seaweed and kelp, sets the case study to test the “extended modelling” approach expressed above.

Sydney Harbour has been chosen as Bio-shelters’ site. Sydney Harbour is an area of remarkable biodiversity; still, due to urban development along the harbour foreshore and due to the industrial heritage of the harbour particularly west of the Harbour bridge, water quality and marine biodiversity are at risk. Traditionally a rocky shoreline, many of the species living underwater are complex systems that expand as colonies of seashell organisms such as clams and oysters (Figure 1). These organisms are filter feeders, whose primary contribution in sustaining environmental balance is to clean the water by removing excess nutrients and pollutants. Those systems are extremely versatile, agile and vital in maintaining environmental balance, meanwhile being very fragile and threatened under the existing conditions. Due to disturbing factors (Dafforn et al., 2015) such as human population increase, also pollution and climate change, the ocean is becoming a stressful environment for seashell organisms living on rocky locations as well as for underwater plants. If those systems are continuously subjected to numerous stresses especially those related to human factors, the strain is too much to endure and so they will perish. In response, the project proposes alternative structures aiming to improve the conditions of seashell organisms and alike of plants whose survival is crucial for the ecosystem.

**Approach**

The study involves a large list of specialisations from bioengineering science, marine biology, engineering, computer science and advanced manufacturing working together with designers and architects to apply a computational design-driven strategy. The aim has been to link architecture with engineering and science through a compound understanding of various processes related to computational design.

In analogy to a hypothetical problem in architectural design, this case includes collecting data from biology to describe typologies of marine habitats about the living conditions of various organisms, also information about the site concerning landscape, topology, soil, temperature and sea currents. Sufficient data sets were collected from colleagues of sciences and engineering to establish a three-fold iterative process potentially leading to a site- and organism-specific design outcome. As the project suggests, key parameters influencing the viability of clams and oysters also of underwater plants as
the various occupants are translated to design structures being then prototyped. The process showed a macro- a meso- and a micro- dimension for the project as outlined below:

* MARCO. As macro- input, the team has defined variables and data sets that respond to site location (geospatial data) such as positioning, orientation, exposure to sun and wind, wave impact, topography and material consistency of the shoreline, etc. This data assisted to define early sketches of artificial coral reefs also of seawalls with similar function. As so far the designs have not been site-specific, this input has been set aside for later, until a decision for the site is made causing to adapt the design to a specific location.

* MESO. This has been arguably the most signif-
icant input, directed by the marine biologists of the team to inform the core data sets for this project. The aim has been to define habitat requirements of oysters, barnacles, seaweed and kelp as specific typological features (Figure 2).

* MICRO. The micro- dimension is concerned with questions of materiality for final reef / seawall production. By following upon earlier experiments with seawalls, it has been argued that high PH-level consistencies such as those being similar to concrete could hinder populating the structure. Thus, the material requires special consideration, which is yet to be defined as a mixture made of clay and crushed oyster shells combined with paper particles to add extra porosity as these will eventually be dissolved. 3D printing is chosen as the most reliable fabrication technique to produce same copies of the designs directly from the digital source.

**First experiments**
Given that the marine biologists could provide various data sets within a very short period (in fact, these had existed already as in cvs. format from previous research) the design team could start modelling to produce the first results during the one-week workshop (Figure 3).

In retrospect, interacting with specialisations of diverse background has provided the designing team with valuable insight on how an optimised ‘living quarter’ for oysters, barnacles, seaweed and kelp might look like. Yet, the marine biologists could understand instantly parallels to formations they have experienced in their day-to-day work and hence they provided feedback on how close the data-driven design approach was, compared with nature’s precedent structures. The first designs were designed digitally, then prototyped in miniature size by using 3D printers, as this process was informed constantly by specialists’ feedback. As a start, physical objects were printed using PLA filaments, helping to better understand the produced geometry and shapes. From these series of models of 250x210x100mm, it was clear that a high level of complexity was actually attainable (Figure 4).

Then, one of the models was scaled up to an approximate dimension of 700x350x350mm and printed using a Z-corp dimension printer and ABS material. Overall manufacturing time had extended in this scale to several days of non-stop printing and the process required large quantities of support material as well. This experience provided with an indication on what to expect during fabrication at physical size with materials defined in the micro- dimension. Consequently, the team currently investigates digi-
tally controlled fabrication processes with the use of a CNC mill with custom-made funnel pipe to distribute a clay / oyster shell mixture (Figure 5).

CONCLUSION. MULTI-AGENT SYSTEMS AND DYNAMIC DATA INPUTS INTO DESIGN
This study aims to reinforce the idea that employing advanced computational techniques such as dynamic simulation and real-time testing currently applied in architectural design research is suitable for a wide range of scenarios including our urban environment and the broader ecosystem. For example, there are many analogies and similarities between human settlements and colonies of marine organisms, particularly in the established relationships with the environment, whether natural or artificial, or both. The analogies are revealed as soon as a design problem is approached via systemic logic, described by data inputs and the relations between them. Especially with the aid of advanced computational tools currently available, design of any kind, whether of an architectural, urban or environmental focus, may be analysed to a set of variables represented by agents interacting with each other and so having their influences registered onto form.

In examining the above, this paper discussed the recent findings of Bio-Shelters, an interdisciplinary project being about the development of reef habitats and the applicability of architectural methods combined with advanced computation to inform the design process. First, it identified the conditions allowing marine ecosystems to survive. These have been translated to their attributes concerning typological features, relative positioning and materiality. Dynamic simulation techniques have been employed to test artificial reef structures as multi-agent systems whose formal and other characteristics are driven by real-like scenarios. Then, the paper presented a series of alternative design structures providing a safe environment for these organisms to breed and to thrive. In assessing the results, this paper has acknowledged the efficacy of extended modelling techniques to drive the process from the early until the final stages of design. Due to full parametrising, it has been possible to adapt the produced schemes to different conditions by performing tweaks of the initial data to affect the outcome. Additionally, dynamic simulation and real-time testing have offered accuracy in each phase of development. Later, prototype models scaled and at physical size will be built and placed at natural locations of Sydney Harbour. The designs will be further examined with regards to feasibility and performance, as this will assist to finalise shape, fabrication techniques, materiality and on-site placement methods.

ACKNOWLEDGMENTS
The Chief Investigators and authors of this paper would like to acknowledge the valuable support from a large and very diverse research team:

For Computational Design: Rebekah Araullo, Eliot Rosenberg, Thomas Walden (all from University of New South Wales, Computational Design);
for Marine Biology: Beth Strain (UNSW, Science), Alex Goad, David Lennon (both from Reef Design Lab), Melanie Bishop, Vivian Cumbo (both from Macquarie University);
for Bioengineering Dr Andre Pereira;
for digital and robot fabrication: Dr Kate Dunn, Melinda Wimbourne, Marjo Niemela;
for advanced 3D printing: Dr James Gardiner.

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