Developing a Complex Knowledge System for Architectural Design Education

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Abstract: Going beyond the confines of single disciplines is a hallmark of late C20th and C21st knowledge systems. Contemporary biological and ecological reconceptions of Architectural Design, as a complex dynamic system, illustrate such movement. However, this shift is not only of interest for the new transdisciplinary knowledge system it creates. Serendipitously, it might also make possible another fruitful synergy: between Education and Architectural Design – for Education, too, has recently explored a biological substrate to explain and understand learning. This paper arises from a doctoral study that set out to investigate this synergy, asking, in essence, whether Education is a designing discipline. Here, we lay out a potential basis for synergy between the two disciplines, from which the research design and methodology of this doctoral study was derived. We give some brief general insights into the study's preliminary findings insofar as they address the viability of this potential synergy and conclude by exploring the implications for architectural design education that could follow from such a synergy.

Keywords: Architectural Design Education, Transdisciplinary, Complex Dynamic Systems, Generative Learning

Introduction

A HALLMARK OF contemporary architectural design is its transdisciplinary synergy with biology and ecology. At the turn of the 20th century, Frank Lloyd Wright placed architectural design in nature and buildings as extensions of their environment (Steele, 2005). His concept of 'organic architecture' involved designing from 'within outward' to intuit human nature in a building, and to begin understanding the environmental energy flows and conditions of the physical context (Wines, 2000). At the cusp of the 21st century, emerging technological advances are enabling transdisciplinary investigations into the ecological and biological basis of architecture (Hensel and Menges, 2006a; Hensel, 2006a, 2006b, 2006c). Architects explore interactions between buildings and their local, and broader regional and global environments (including site and changing climatic conditions). They investigate a building's place in urban networks, as a dynamic knowledge system alongside the human experiences and uses of these buildings as environments in their own right. For example, the architectural practice of Foster and Partners conceives of buildings as systems (Duffy, 2000) where there is 'a search for humane architectural qualities' (Giovannini, 2003, p. 526) and the development 'of relations not only between a building and its natural and man-made surroundings but also between the building and its users' (Abel, 2003, p. 15). Architects learning in a post-professional Master's programme (Verebes, 2008) investigate the ways in which 'associative design systems can control local dynamic information to effect and adjust larger urban and global life-processes' (p. 66) and electronic networks can 'make possible life-like forms of feedback between the built environment and its users' (p. 134). Technological models test a conception of

> architecture as ecology, involving dynamic and varied relations and mutual modulation between material systems, macro- and micro- environmental conditions, and individual and collective inhabitation (Hensel and Menges, 2006b, p. 63).

Such synergy is certainly of interest in its own right, as it is producing a burgeoning number of exciting sustainable and humanitarian architectural designs, including those examples we describe in this paper. However, we are interested here, in particular, in how this synergy might foreground another – between Education and Architectural Design. If it can be shown that this second synergy exists, then a coherent foundation for theorising Architectural Design Education will have been laid.

So, we begin by describing a set of design cases, then analysing them to identify particular salient features of contemporary architectural designing. Having characterised architectural designing in this way, it will then be possible to set these insights alongside a frontier edge conception of learning (a biologically based generative theory of learning

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(Edelman, 1992, 1993; Plotkin, 1994, 1997, 2002, 2004; Schaverien and Cosgrove, 1999, 2000)) to explore whether, in principle, the potential exists for a significant synergy between Architectural Design and Education.

We conclude with some speculative implications of this exploration's findings now arising from the first author's doctoral study. In particular, we anticipate strong, newly possible foundations for learning, teaching and researching in Architectural Design Education.

Architectural Designing: Three Contemporary Cases

The following three cases allow representative and yet diverse insights into contemporary architectural designing:

1. The Modern Education and Training Institute (METI) School, Rudrapur, for its humanitarian design,
2. 30 St Mary Axe, London, as a sustainable urban skyscraper, and
3. Beijing's National Aquatic Centre for the 2008 Olympic Games (the Watercube), as a transdisciplinary collaborative design.

1. Modern Education and Training Institute (METI) School

The Millennium Development Goals and the 2005 UN World Summit affirmed the determination of Heads of State and Governments to respect basic human rights, including with regard to shelter (United Nations, 2000, 2006). Within the constraints of limited global resources, climate change and projected population growth, architectural scholars are recognising and making explicit their discipline's foundational humanitarian goals. Recognising that only 3% of buildings are architect-designed (Coulombel and Fidler, 2007), our own local professional institute, RAIA (The Royal Australian Institute of Architects), focused its members' thinking on both argument and opportunity once architecture is reconceived for the 95% (Nield, Coles, Beale and Pholeros, 2006). Architects may well be most needed where they can least be afforded (Architecture for Humanity, 2007). A plethora of international initiatives (Emergency Architects (Coulombel and Fidler, 2007), Architects without Frontiers (Charlesworth, 2006), Architecture for Humanity (2006, 2007) and Architects for Aid) now addresses the challenges of reconfiguring architecture to contribute to 'the wider social and environmental health' of nations (Charlesworth, 2006, p. 19).

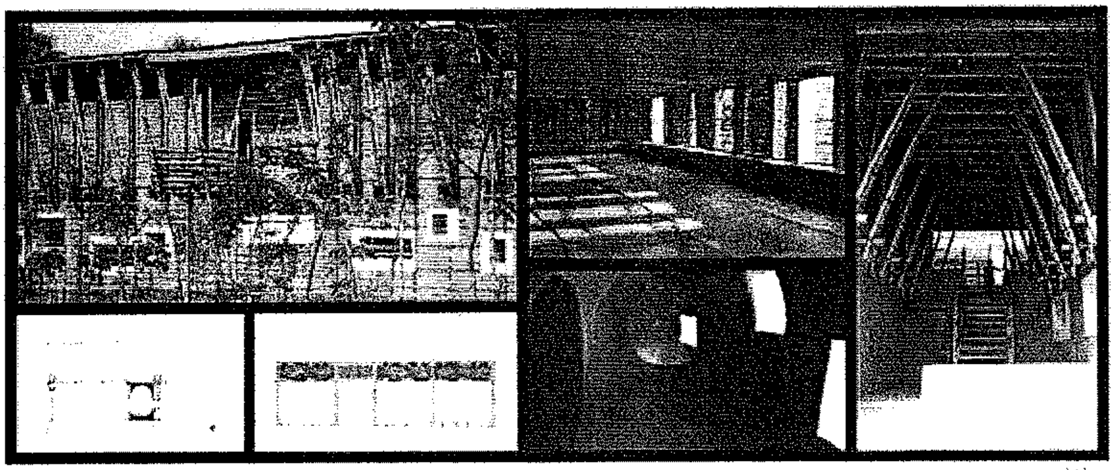
Anna Heringer, in consultation with Eike Roswag, designed the METI School in Rudrapur, a rural village in north Bangladesh, with support from the development agency (NGO) Dipshikha. Years earlier, Heringer had spent a gap-year in Bangladesh before commencing architectural studies at the University of Arts, Linz. She undertook a diploma project in which she returned to her earlier experiences of Rudrapur and her contacts with METI and Dipshikha (Lim, 2007),[1] aspiring to design and build a school and resulting in 'a profound dissertation, a high-calibre scholarly and artistic analysis' (Gnaiger, 2008).[2] In their designing of the METI School, Heringer and Roswag's efforts went beyond providing basic shelter to building sustainable communities (Stohr, 2006; Ashraf, 2007; Finch, 2006): 'We believe that architecture is more than shelter. It is intimately connected with the creation of identity and self-confidence. And this is the basis of development' (cited in Lim, 2007). In the diary she kept at the time, Heringer recorded playful sketches as she explored her question – 'Spaces for children: What do kids like ... (what did I like?)' (Heringer, 2008).[3] So in the first instance, this 'joyous and elegant two-storey primary school ... emerged from a deep understanding of local materials and a heart-felt connection to the local community' (Jury citation, Aga Khan Award for Architecture, 2007, p. 148).

The METI philosophy of 'learning with joy' respects the unique way that each individual learns, encouraging children 'to develop their own potential and to use it in a creative and responsible way' (METI School, 2008). The building provides a variety of spaces for such learning to occur, and creates two very different learning environments through its material use of mud and bamboo. The mud construction of the three ground-level classrooms ensure a comfortable climate and their organically shaped cave-like spaces provide meditative and playful learning environments (Aga Khan Award for Architecture, 2007): the soft interiors of these earth spaces are 'for touching, or nestling up against for retreating into for exploration or concentration, on one's own or in a group' (Ashraf, 2007, p. 116). In contrast, the first floor open classrooms with their bamboo con-

[1] Along with three fellow students, Heringer spent 'three months in the field [Rudrapur] driven by the questions "How does a village work?" "What is a village? - A town in a smaller scale or [is it] an own particular organism?" "What are the links between architecture, the local economy and society?" "How important is culture?" "What are the problems, the potentials, the future challenges of Rudrapur - and of rural areas in general?"' (Anna Heringer, 2008).

[2] Heringer's diploma project was conducted under Professor Roland Gnaiger.

[3] Later, alongside images of the completed building, Heringer describes this exploration in words: 'What kind of spaces do children like? As a kid I loved to hide in bushes or to build caves with textiles or branches and I also loved to climb trees to enjoy the view and dreamt of a house high up in the crown...' (see photograph 9, Handmade School (Anna Heringer, 2008)).



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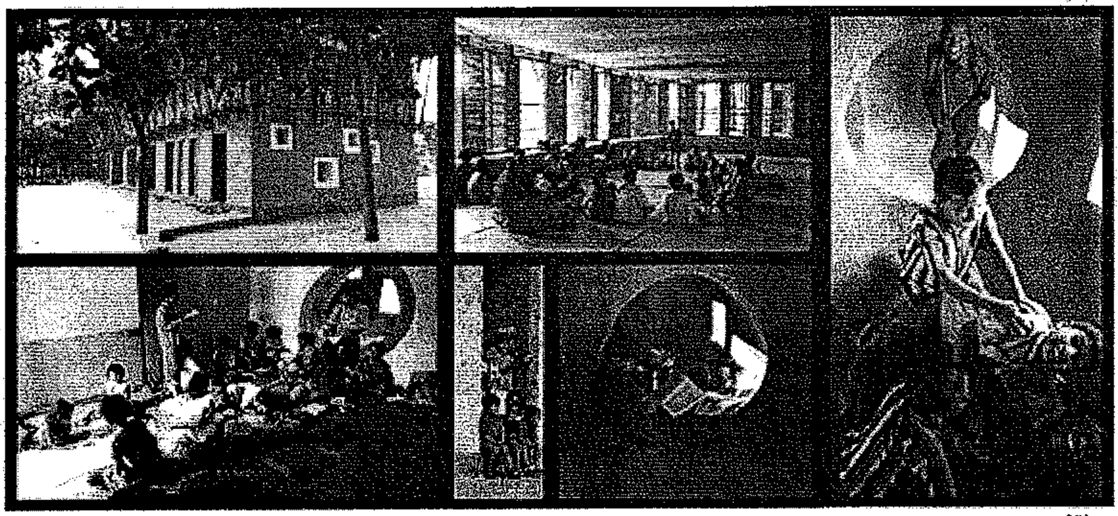

[2]

[3]

Figure 1: METI School. [1] Next to her playful exploratory design sketches of 'Spaces for children: What do kids like ... (what did I like?)' Anna Heringer wrote: 'tents with textiles or leaves – or the cave in the tree at Heilbrunn– or the mysterious cave next to our garden – and of course our towers in the scout camp, 12m high – or the one with two platforms' (2008). [2] The METI philosophy: 'There are two dimensions in the education system: formational and life-oriented education. Aims are: to help bring out the best in a child, to prepare and form individuals with the capacity of logical, analytical as well as holistic and creative thinking, to promote leadership and managerial skills from childhood' (Lim, 2007). [3] A Bangladeshi visitor to the building site 'complains vehemently about how little the "stupid earth" can withstand. His house also collapsed the night before after only 8 years ... [He says,] "So, if it really is possible to make buildings out of earth that last ten times longer then that would be a major improvement"' (Heringer, cited in Ashraf, 2007).

struction are light and airy, taking a vantage of the wider countryside. The walls, which are made of bamboo strips, allow natural ventilation and sunlight to be regulated through the use of shutters and cast interesting diffused light patterns (Aga Khan Award for Architecture, 2007). Colourful sari canopies hang at their ceiling level. It has been described as 'a building that creates beautiful, meaningful and humane collective spaces for learning, so enriching the lives of the children it serves' (Jury Citation, Aga Khan Award for Architecture, 2007, p. 148).

The school was built in four months by local craftsmen and the wider community using traditional methods and materials but these were adapted in new ways (METI School, 2008). The abundant local materials of loam, straw, bamboo and rope were used and bricks for the foundation were sourced from close to the village. There had however been early resistance to the architects' proposal of a mud-walled school building as such mud construction is much maligned in the area (Aga Khan Award for Architecture, 2007). So the architects worked with local craftsmen to utilise the inherent qualities of these local materials and to combine them inventively with improved construction techniques (for example, introducing a bamboo load bearing structure to the construction and a damp proof foundation) (Nussbaum, 2006; Pawlitschko, 2007). These innovations addressed the problem of earth buildings being washed away during the monsoon period, generated the first two storey building in the village and extended the previous average ten year life span for a farmer's mud shelter (Aga Khan Award for Architecture, 2007; Nussbaum, 2006; Pawlitschko, 2007; Finch, 2006). The ecologically sustainable design of the METI School and the process of its making seeded new ideas about how 'building with earth can inspire for improving the quality of living for the poor in rural areas' (Ashraf, 2007, p. 116; for example, Slessor, 2008; Anna Heringer, 2008; Kayes, 2008).

Humanitarian Design: From Homogeneous to Heterogeneous Spaces

Modernist architects developed homogeneous spaces characterised by uniformity, universality and homogeneously conditioned interiors (Hensel and Menges, 2006b). However, the designing of such heterogeneous spaces as the METI School harnesses varying human activities, individual and collective choices, diverse values, renewable resources and dynamics. So, designing for heterogeneity goes beyond designing primarily based on function. It progresses on the basis of particular and changing values (for example, the core values of the people for whom it is being built) alongside an understanding of the nature of human activities (for example, the METI Education approach which espouses a particular view of learning) thereby hedging a fit between people and their environment. In this process, existing values can also be challenged, as is evident in the METI case. The generative capacities of local materials emerged from inventive construction techniques which resulted in this community's revaluing of its abundant renewable resources (mud, bamboo). Such use of materials was integral in the development of these heterogeneous spaces whilst at the same time it represented a value change and the creation of a new knowledge system: children were learning in a built environment that itself was an innovative embodiment of new community values.[4]

2. 30 St Mary Axe

The Industrial Revolution heralded a rapid growth of urbanisation and the development of cities accommodating the population explosion of the 19th century (Frampton, 1992). In 1800 only 3 percent of the world's population lived in cities, increasing to 13 percent in 1900 and 50 percent today with the projected urban population growth according to current trends reaching 60 percent (or 5 billion people) by 2030 ('Survey: The world goes to town', 2007). Such growth presents challenges not only to urban sustainability but also related to global implications of these cities (Bugliarello, 2008). Buildings now account for two-fifths of the world's energy use (emitting 50 percent of its greenhouse gases), one-sixth of its water consumption, and one-half of its waste streams, and new construction is consuming three billion tons of raw materials each year (Albers and Fettig, 2006; Braungart, 2002). Cases such as 30 St Mary Axe reflect the current pressing agenda for generating ecological and sustainable high-rise urban building. For example, the Big and Green exhibition (Gissen, 2002) documented fifty projects which advocate for 'cutting edge practices in large-scale sustainable design [by] finding ways to create buildings that consume less energy in their day-to-day operation, use renewable materials, and rely on natural means to ventilate and illuminate their interiors' (Henshaw Jones, 2002, p. 6). More recently, the Skyscraper Museum and the New York Academy of Sciences

[4] Furthermore, researchers using technological models are now exploring the potential of 'richly varied heterogeneous spatial arrangements, profusely conditioned by microclimatic variation, that provide for migratory human activities and dynamic social formations' (Hensel and Menges, 2008b, p. 105), spaces that provide 'choice for the individual and [help] to sustain individual and collective itineraries of habitation that can also evolve over time in tune with the dynamics that facilitate them' (Hensel and Menges, 2008b, p. 105). Variation is designed into such heterogeneity, and then designs are evaluated for their performance (for example, Bollinger, Grohmann and Tessmann, 2008; Hensel and Menges, 2008a, 2008c).

(2007) lecture series presented cases of state-of-the-art sustainable skyscraper design and green building technology. In this milieu, today's skyscrapers are 'the lab benches for sustainable-technology innovation' (Russell, 2004b).

The architectural firm Foster and Partners collaborated with the client Swiss Re to design 30 St Mary Axe, a skyscraper that utilised the historic site of the former Baltic Exchange in the centre of London (von Arx, 2006a). Swiss Re was particularly interested in 'an environmentally progressive building', reaffirming their company's strong commitment to sustainability (Powell, 2006, p. 71). As the Swiss Re director for this building project, Sarah Fox, states: 'We are in the reinsurance business. For us, sustainability makes excellent business sense because we pay claims on behalf of clients for floods, heat waves, droughts. To the extent that these claims are related to global climate warming, it is only prudent of us to contribute as little to it as possible' (Russell, 2004a). In valuing innovation, Swiss Re was willing to go beyond a conventional box tower and explore radical design possibilities with the project's architectural team (Powell, 2006).

Foster is known for setting design priorities to achieve 'a more humanely social work environment' (Russell, 2004a) and for believing in 'the importance of the social focus, the heart of the building, the way in which it can change the quality of people's lives' (Foster, 2005, p. 14). For example, he designs for informal social spaces and amenities that staff value, that engender a sense of community and that encourage collaborative work – characteristics evident in the skygardens in the Commerzbank tower (Frankfurt, Germany) and the roof level of the Willis Faber and Dumas building (Ipswich, England) with its glass restaurant pavilion set in a landscaped garden (Foster, 1977). 30 St Mary Axe presented an opportunity for Foster and Partners to continue to investigate the social dimension of workplace design.

Over three years, and not without controversy, Foster and Partners worked with the Corporation of London Planners, the Royal Fine Art Commission and English Heritage as they developed and refined a range of proposals (Powell, 2006; von Arx, 2006b). The architects wanted to create a public realm around the new building where previously the historic Baltic Exchange had filled the site and to open up new pedestrian routes (Russell, 2004a; Powell, 2006). A circular building would enable such a communal area to take up much of the site. Plazas at the base of tall towers had in the past been inhospitable places for people because of the winds generated. A circular shape would minimise such downdraughts and turbulence at ground level (Stansfield, 2004; Foster and Jenkins, 2007; Wells, 2005; Russell, 2004a). The aerodynamics of a circular shape also influenced the tower's heat loss and solar gain (Powell, 2006). Unlike the traditional crowns of buildings, the surface of the 30 St Mary Axe proposal curved distinctively to an apex with uninterrupted 360 degree views suggestive of a cockpit (Foster, 2007; von Arx, 2006a).

Circular office buildings however can produce awkwardly shaped working spaces and offices that can be difficult to occupy and let (Gregory, 2004; Powell, 2006). By conceiving of rectangular office floors within such a circular tower, the Foster team could create six radiating 'fingers' from a central core (including lifts, stairs, washrooms and service risers). In between these six rectangular fingers, six triangular spaces as lightwells extended vertically for the full height of the building (Powell, 2006; von Arx, 2006b). These fingers and triangular spaces would use the same floor plate but vary in size as the building tapered from base to tip, thereby containing construction costs.

When atria were devised in these vertically straight triangular spaces, the vertiginous nature of such chasms became evident and violated regulations. By rotating each of the floors by 5 degrees in succession, the architects achieved compliance (Wells, 2005). The resulting triangular stepped atria with their overlooking terraces and prime views opened out many opportunities for different social spaces and interconnectivity (Russell, 2004a). An external diagrid would respond to the radical form of the building, ensuring stability, resisting wind forces (usually the role of the building's core), providing column-free office spaces and increased flexibility as well as structurally complementing the spiralling atria (von Arx, 2006b; Foster and Jenkins, 2007; Powell, 2006). To deal with fire safety regulations, opening vents were needed in the atria's facade to extract smoke rapidly. However, these were then developed into opening windows to bring fresh air into the building. The spiralling atria's initial direction was reversed to utilise the prevailing south-west winds and maximise the potential for ventilation. Use of tinted glass for the atria façade to lessen the glare and solar gain gave the building a distinctive aesthetic appearance, inspiring its official logo (Powell, 2006). The double skin of the building created an intermediate environmental zone between the outer skin of the building and the office floors. These ideas grew out of the principles of the Climatroffice (which included a triangulated glass skin), a concept Foster had explored many years earlier (in 1971) with Buckminster Fuller (Foster, 2000). Only recently, with the advent of technological tools, could such complex structures and geometries be modelled and insights gained into the implications of its ecological design (Hwang et al, 2006a; Foster, 2005; Abel, 2003; Goulthorpe, 2003; Stacey, 2004).

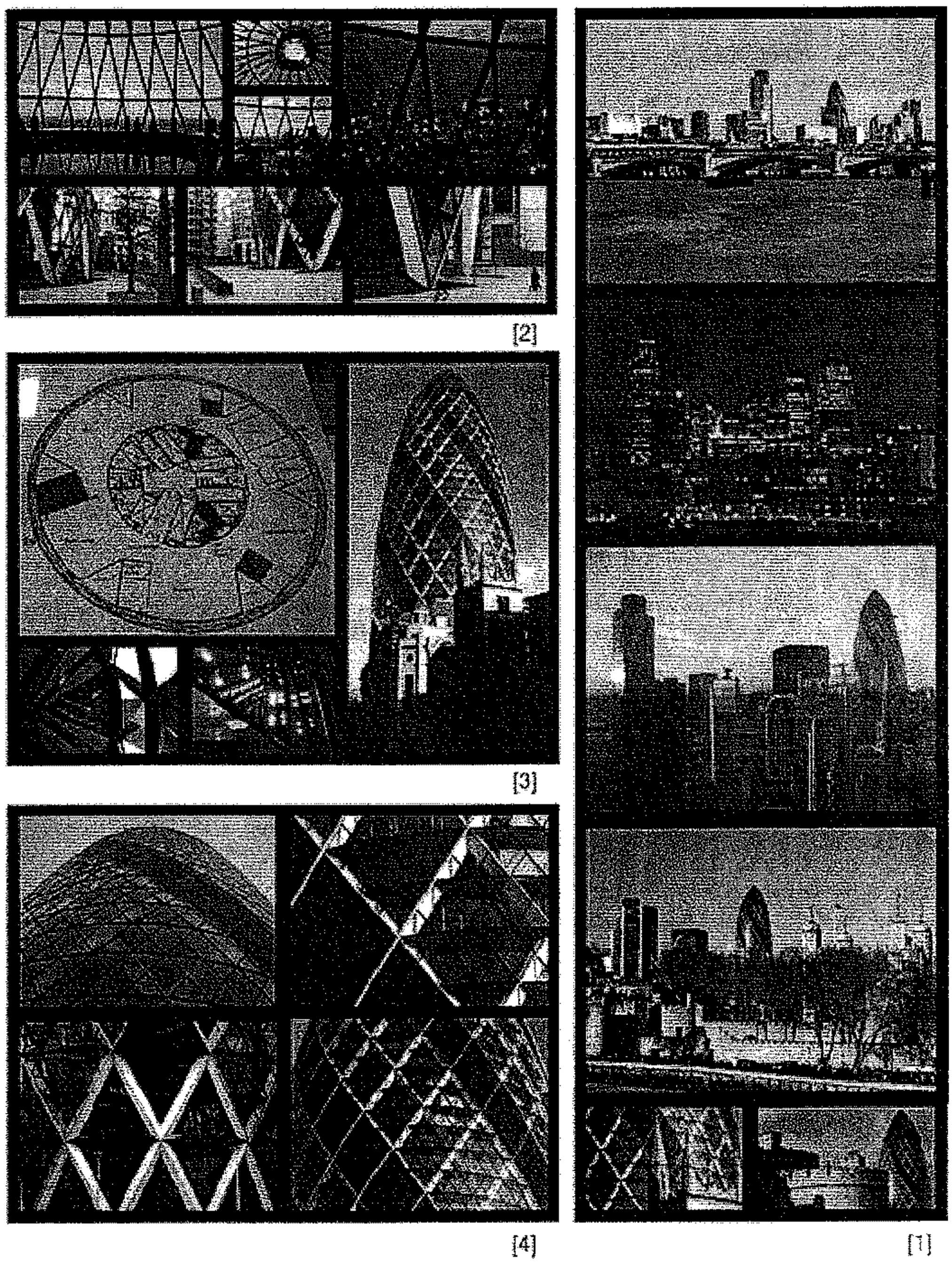

Figure 2: 30 St Mary Axe. [1] Skyline and history: 'London should be able to build towers like [30 St Mary Axe] without destroying the memorials of its past' (Jenkins, 2007). [2] Social spaces: 'The viewing gallery at the top is, at night, like a planetarium' (Jenkins, 2007), and 'the plaza around the tower measures a total of 2000 square metres – equivalent to eight tennis courts' (Powell, 2006). [3] 'Successive floors are rotated, allowing voids at the edge of each floor plate to combine in a series of spiralling atria or 'sky gardens', which wind up around the perimeter of the building. Socially, these green spaces help to break down the internal scale of the building while externally they add variety and life to its facades. They also represent a key component in regulating the building's internal climate' (Foster, cited in Merrick, 2004). [4] 'Diagrid structures echo naturally occurring molecular forms and are inherently strong and efficient … Light, rigid and resilient, they allow great formal and structural freedom' (Foster and Jenkins, 2007).

Generative Designing: From Building to Environment

Architects today conceive of 'the built environment as a substrate and catalyst of motile, mutable and feedback-based relations between habitat and inhabitants' (Hensel and Menges, 2008a, p. 7): they recognise that designing for multiple influences and responsiveness involves various environmental dynamics such as cultural, physical and energetic factors.[5] In the case of 30 St Mary Axe, for example, imaginative ideas were generated in confluence in the designing and acted as dynamic substrates and catalysts for how this building might begin operating as a sustainable urban system.

Energy dynamics. As design ideas were generated, their dynamic relationships with climate emerged:

- A system of atria could act as the building's 'lungs' drawing in fresh air, providing natural ventilation and reducing the need for air-conditioning.
- A double wall façade could work with the atria as part of the office-extract ventilation system.
- A distorted spherical form could be a means of reducing solar gain.
- Lightwells could bring daylight deep into the floor space, even to those positioned closest to the core (Powell, 2006).

By selecting for such design ideas, 30 St Mary Axe is consuming only half the energy in operation comparative to its environmentally sealed neighbours (Gibson, 2008).[6]

Historical, physical and social dynamics. The modernist architectural landscape had arguably created 'relentlessly dull buildings owing nothing to a sense of place and everything to their internal logic. Modern architecture had become insensitive to the lives and values of those it purported to serve' (Glancey, 2000, p. 198). In central London, well-established planning practices and historical precedents had restricted the building of skyscrapers. However, tall buildings as distinctive landmarks and architectural icons have come to represent global stature and to project a city's image as a cutting edge location for global capital and economic community (Charney, 2007). Such contemporary design drivers and Swiss Re's investment in an innovative skyscraper for 30 St Mary Axe provoked planning changes (Sudjic, 2001; Bell, 2007). Now built, 30 St Mary Axe with its distinctive aesthetic has sparked the imagination and interest of the public and their respect as a dynamic landmark (Heathcote, 2008; Jenkins, 2007; Gregory, 2003; Merrick, 2004).[7] Moreover, it has set a precedent of innovative, memorable architecture and high quality office space for subsequent tall buildings in the City of London (Charney, 2007; Powell, 2006).[8]

Economic dynamics. These dynamic benefits could occur on different time scales:

1. An environmentally progressive building made good business sense for Swiss Re by enacting the company's integrity on two fronts: as a reinsurance company its concerns encompassed economic and societal costs of environmental degradation; and it would address such issues through an innovative approach to 30 St Mary Axe, thereby tangibly representing its values – 'Swiss Re is about judgement and creativity [says John Coomber, Swiss Re CEO] ... We're an ideas business and the London building epitomizes what we stand for' (Powell, 2006, p. 11).
2. Once built, 30 St Mary Axe could profit from the perceived market benefits of its technologically sustainable design (Kaji-O'Grady, 2007). Also, according to the US Green Building Council, buildings that are sustainable have an initial higher market value of 7.7 percent (Frechette and Gilchrist, 2007).
3. It would use less energy thereby reducing the running costs of the building over its lifetime.[9]

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[5] Furján (2007) describes such self-organising behaviour, where "building' gives way to 'ecosystem', to a built organization that operates at the level of vivisystems – dynamic and complex systems that learn, adapt, evolve, and mutate in response to the feedback of environmental conditions' (p. 116).

[6] Architects like Ken Yeang through their many projects now in operation demonstrate that tall buildings can be reconceived as environmentally sensitive mechanisms (Lord Norman Foster, cited in Yeang, 2007), based on bioclimatic principles, with an active relationship to their surroundings (Yeang, 1994, 1996, 2007; Yeang and Powell, 2007). More recently, the design of skyscrapers has focused on how buildings can generate their own energy: for example, the Pearl River Tower (in Guangzhou, China) set to be completed in 2010 and designed to operate as a 'net zero energy skyscraper', utilising energy it harvests from the local environment (Low, 2008; Stewart, 2006).

[7] Arup Associates' set of unified principles highlight such design changes: for example, 'Whole life sustainability places people first. It enhances the cultural value systems found within different locations, rather than creating modernist models that expect people, cities and places around the world to behave in identical ways' (Brislin, 2008, pp. 20-21).

[8] Architectural firms such as Skidmore, Owings & Merrill (SOM) have recently taken a systems view to experiment with context- or place-specific architecture, arguing that what emerges is a unique aesthetic: 'if you create ... a building that performs in the right way in a particular environment ... you can create a language of architecture that is place-specific' (Wimer, 2007).

[9] For example, in their analysis of the designing of Pearl River Tower, SOM architects outline how the introduced sustainable technological strategies with their initial high capital cost investment pay back within 4.8 years after which they continue to create revenue over the life of the building (Frechette and Gilchrist, 2007). Such findings echo Foster's convictions that good design can be gauged in economic terms over the long term (Foster, 2003) and reaffirm earlier reports regarding the costs and financial benefits of green buildings (Kats et al, 2003).

3. Beijing's National Aquatic Centre

A hallmark of late 20th and 21st century disciplines is the recognition of increased fluency across disciplinary boundaries to collaboratively address the complex issues of our age (Wilson, 1998). For example, in the 1960s the architect Frei Otto collaborated with the biologist and anthropologist Johann-Gerhard Helmcke to build on his interest and work in lightweight structures. Together, they provided ways of exploring nature as a source of form-finding principles and devised experimental modelling into the self-organising processes of material systems (Otto, 2004). Such lightweight structural developments reduce the material resources required and enable greater versatility. More recently, the perceived benefits of such generative and experimental collaboration has mobilised leading firms and research groups to form multidisciplinary teams. For example, in the engineering firm Arup and Partners their Advanced Geometry Unit comprises an architect, three engineers, a mathematician and a scientist (permanent members with individual multidisciplinary backgrounds) working on basic research and connected to another thirty Arup engineers working on specific projects in the field (Walker and Emergence and Design Group, 2004). Similarly, the globally dispersed research group Ocean operates as an interdisciplinary and interdependent network across diverse fields to influence the making of the human environment (Ocean, 2008; de Manincor, 2008). The Beijing Olympic Swimming Centre, too, highlights how transdisciplinary collaboration might influence a building's innovative development (Bilmon and Bosse, 2007).

In early 2003, following Beijing's successful bid for the 2008 Olympic Games, the Municipality of Beijing announced a limited design competition for the Olympic Swimming Centre, a condition of which was inclusion of Chinese partners (Orr, 2007). This formed part of a wider, gradual and pragmatic approach to generate technological innovation from international cutting-edge knowledge and stimulate its domestic development (Yao, 2007). The multidisciplinary consortium of PTW Architects, Arup (Engineers, Australia) and CSCEC-SDI (China State Construction Engineering Corporation – Shenzhen Design Institute) was shortlisted as one of the ten international teams (Carfrae, 2007).[10] What follows is a brief account of their initial designing leading up to their competition entry.

Early competition proposals from the PTW architects explored fluid, organic forms such as curvilinear roofs resembling petrified waves of water (Orr, 2007; Ryan, 2008). However, these curvilinear forms seemed to some of the cross-cultural team to be inappropriate for a country whose temples, monuments and ancient cities are based on the geometry of the square and for a cultural tradition that favoured axial arrangement and rectilinearity in the built environment ('John Bilmon describes the Water Cube', 2007; Orr, 2007; Drew, 2008). The architecture planning team calculated that the entire square site would be needed to fit all the required facilities of the centre (Carfrae, 2007), and a box form for the shape was accepted – a 'Watercube' (Drew, 2008). At that time, the winning bid for the adjacent National Stadium (becoming known as the 'Birdnest') was announced and the complementary Chinese cultural symbolism of the two stadia designs, side by side, became obvious: the 'Birdsnest' was red, vivacious, round – masculine, the yang, or fire; and the 'Watercube' could be square and blue – feminine, the yin, or water (Hwang et al, 2006b; Ryan, 2008).

As a building for water sports and swimming, the inside environment of the Aquatic Centre needed to be hot and humid so that swimmers coming out of the pool would not be chilled. The inside temperature therefore needed to be 28-30 degrees Celsius. The average outside temperature of Beijing is 14, and ranges from below 0 in winter up to 40 in the middle of summer. So, in essence this suggested to the team that the building was an exercise in heating, not air-conditioning. The Arup engineers considered that the most effective way to heat a building was as an insulated greenhouse, which could also deliver the additional benefit of natural light thereby reducing energy-use and reflective glare from the water. With the chlorine from water vapour making for a highly corrosive environment, the engineers thought it would be good if this greenhouse's structure were not inside the swimming pool. So ideally the structure would be in a cavity. Also, a problem in swimming halls is the acoustics, as people having fun make a great deal of noise. Hard finishes and surfaces, like tiles, water and glass, reflect sound and create a very aggressive environment (Carfrae, 2006a; Ryan, 2008).

[10] Years later, after completion of the Watercube, when asked – 'One of the things you said about the building and the competition is that you see Olympic buildings as equivalent to medieval cathedrals in terms of the opportunity for innovation' – Bilmon (PTW Architects) describes the innovative drive in designing such buildings:

> I see the Olympic facilities of the world these days as being the true iconic buildings of the era. They're buildings which reflect the current state of knowledge regarding materiality and technologies, and design trends. And also they indicate, or they provide an opportunity for a country to showcase its own aspirations. And I think that that's been absolutely achieved in the case of China and the Watercube (Ryan, 2008).

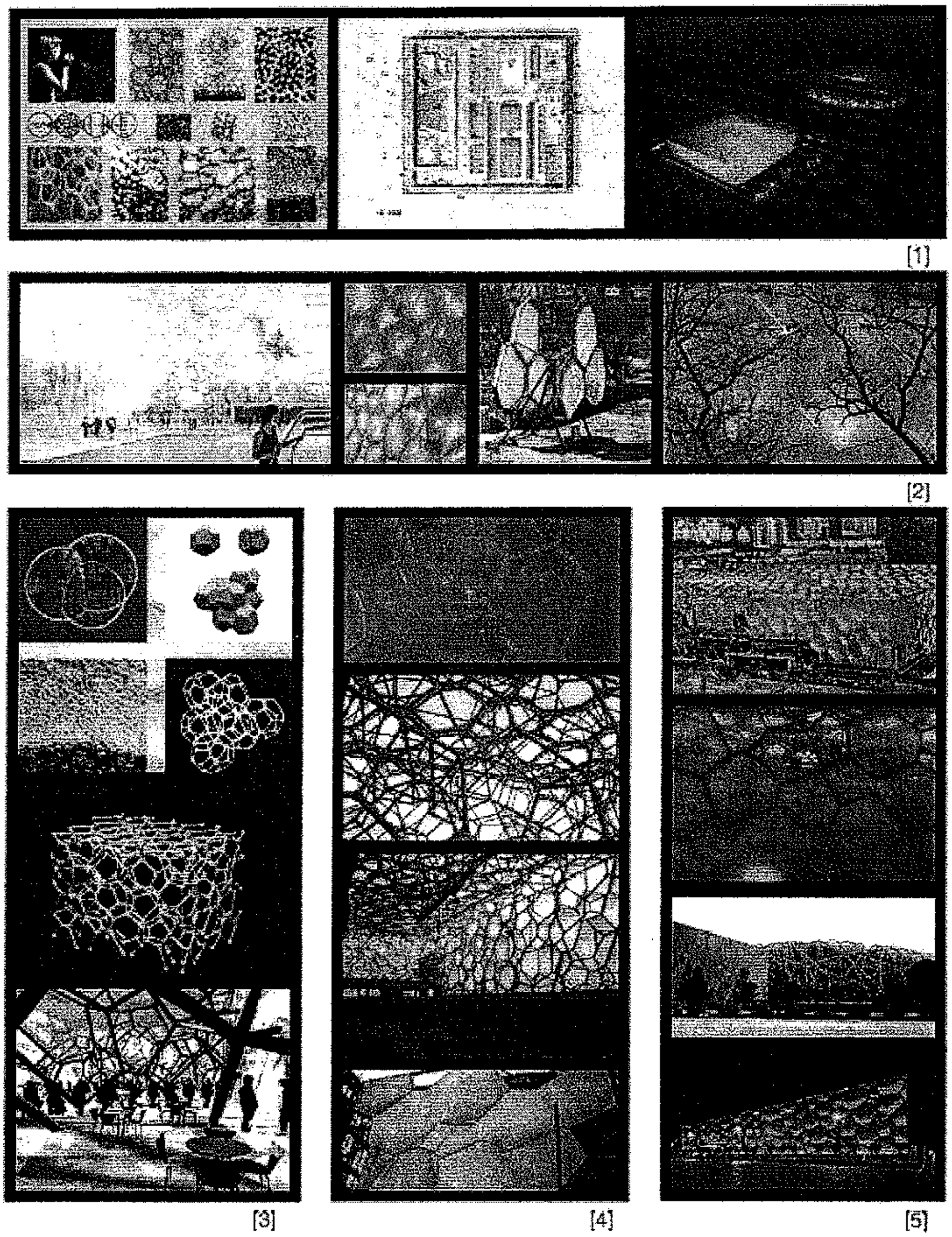

Figure 3: Beijing National Aquatic Centre (Watercube). [1] 'The judging panel made the decision based on two criteria ... whether the project met the needs of the sport itself ... whether the design had distinguishing cultural features and how it fits into the surrounding environment' (Pohl, 2008). [2] ETFE: 'I first came across this material in the early 80s ... At the time I was slightly sceptical about whether it was appropriate to build a building out of gladwrap or something not dissimilar. And yet it's now proved the test of time' (Carfrae, cited in Ryan, 2008). [3] '... this seeming random generation of structure, but it is in fact a solution that is extremely repetitive and highly buildable' (Arup, 2004). [4] 'While Weaire-Phelan provides the geometry of the Watercube, Arup and CSCEC had to figure out how to actually make the building stand up' (Hwang et al, 2006b). [5] The probabilistic nature of designing development: 'In retrospect, having seen the finished building, there are a number of stories here ... we have got an aquatic centre that is made from a box of bubbles – if I was terribly honest, I would say coincidental' (Carfrae, cited in Drew, 2008).

Alongside the initial concept of water for the design, the team then began to consider ETFE as a cladding material (Carfrae, 2007). In the 1970s the fluorocarbon based polymer ETFE was invented for use as insulation material for the aeronautical industry (Talley, 2008; Woyke, 2007). However, its transparency, self-cleaning and structural properties – for example it could be spun into thin, surprisingly durable film and made into sheets or inflated into pillows – generated potential as a building material (LeCuyer, 2008). In 2000 Grimshaw Architects unveiled their Eden Project in Cornwall, with its two gigantic geodesic conservatories covered in ETFE, which received wide acclaim for its engineering feats and created global interest in ETFE for design (Melvin, 2001). In particular, such interest related to the following inherent properties of ETFE for architecture (Woyke, 2007; Talley, 2008):

- compared to glass, it has better insulation properties;
- ETFE foil weighs 1% of a glass panel of equivalent size;
- it is a tough recyclable material;
- durability is more than 20 years;
- when exposed to fire, it softens and shrinks away from the heat creating a natural vent to remove smoke;
- different finishes (transparent, matte) and printed patterns can be achieved on its surface;
- the ETFE system (including its light weight) reduces corresponding structural costs, and;
- it is highly resistant to the weather effects of sunlight.

The PTW architects selected this material for the Aquatic Centre design because it seemed to meet their aesthetic, environmental and engineering requirements (Rappaport, 2006; Carfrae, 2006b; Hwang et al, 2006b; Orr, 2007).

So, the Aquatic Centre was to be a square form that would operate as an insulated greenhouse, using an ETFE façade and housing a steel structure within a cavity. The question arose as to what this structure should be. A triangulated space frame offered a possible design option but the team realised it would not win them an international design competition (Carfrae, 2006b). As well as exploring innovative possibilities for the cube's façade, turning to nature for ideas about water and bubbles, the team revisited an earlier experimental architectural design: the Bubble Highrise in Berlin (Weinstock, 2006), with its circular pattern of cladding. They conceived of circular patterns of ETFE bubbles, with vertical tubes. The intersections of the roof with the walls could not be resolved elegantly using this idea, and so it was discarded (Carfrae, 2007; Rappaport, 2006). However, from that idea Tristram Carfrae, an Arup engineer, was to ask: 'If cylinders do not work, what else will? What sorts of shapes fill three-dimensional space uniformly, besides the somewhat prosaic triangulated space-frame?' (Carfrae, 2007). 'What structure goes around corners? How does structure inhabit space?' (Carfrae, 2006a).

In his investigations, Carfrae came across the Kelvin foam bubbles but soon realised that its structure did not have an organic quality they were looking for, which led him to the work of theoretical physicists, Weaire and Phelan (Ball, 2007; Drew, 2008). These scientists explore what is the most economical way to divide space into cells of equal size with the least surface area between them (Senses, 2007; Weaire, 1994, 2008). Such ideas would subsequently enable a creative shift from Frei Otto's explorations of soap bubbles as film-like minimal surface structures (for example, the roof of the 1972 Munich Olympic Games Stadium) to an examination of the bubble connections in foam (for example, soap film meets at stable tetrahedral angles) (PTW Architects, Sydney et al, 2007). By carving a slice at an angle from an infinite array of incredibly regular and repetitive geometry of the Weaire-Phelan foam, the team generated a surface with a random, organic pattern (Hwang et al, 2006b). All that was then needed was to carve out voids from underneath the foam to create spaces for the halls in the program. This three dimensional structure would '[unite] the load-bearing function, the facade and spatial enclosure in a single element, creating an extremely efficient form of construction that [could] withstand earthquakes and that [required] roughly 30 per cent less steel than a column-and-beam system' (PTW Architects, Sydney et al, 2007, pp. 1472-3). In Carfrae's (2007) words: 'Our search for the most efficient way of subdividing space had led to a structure based on the geometry of an array of soap bubbles, clad with plastic pillows that look just like bubbles – to house the water at the heart of an aquatics centre! Our team were convinced the scheme would win' (p. 48).

Developmental Designing: Realising Complex Material Systems

The development of new materials can introduce changes to the architectural designing system more widely, including construction (Addis, 2007).[11] Experimentation and research into the behaviour of materials has deepened understandings of their inherent qualities (for example, Hensel and Sunguroglu,

[11] In particular, according to Hensel and Sunguroglu (2008), 'Architecture is a material practice. Materials make up our built environment, and their interaction with the dynamics of the environment they are embedded within results in the specific conditions we live in' (p. 36).

2008; Weinstock, 2006). In the case of the relatively new material ETFE, the growing architectural experimentation (including the Watercube) of its unique characteristics related to structural behaviour, light transmission, insulation, acoustics, fire engineering and environmental modification is unleashing its value and importance as a building material (LeCuyer, 2008).

However, in its development, the Watercube innovates on yet another level. The design team:

- takes the spatial idea of an aquatic centre that creates a particular subjective experience, one of being in a surreal underwater atmosphere with filtered, dappling light (Bosse, cited in Hwang et al, 2006b, p. 70).
- selects a box form that complements its environment culturally and physically.
- conceives of an insulated greenhouse that provides optimum climatic conditions.
- explores ETFE as a sustainable, lightweight material that could clad this large scale greenhouse.
- asks a different question about how structure might inhabit space as well as have a random, organic aesthetic that generates the complex material system for the Watercube.

The Watercube's façade, structure and form combine into a single element using a 'complex lightweight structure with a multiple layered ETFE skin' (Bosse, cited in Hwang et al, 2006b, p. 70). Just as in biological organisms the form, structure and material are integrated, interdependent and act upon each other, so, in the Watercube, it does not make sense to think of one to the exclusion of the others (Weinstock, 2006).[12] When asked – 'Though the Watercube structure is revolutionary, how is it similar to traditional construction methods and techniques where a certain material is both structure and facade?' – Chris Bosse (PTW) replied:

> Cathedrals are probably the best example of this older idea, whereby structure, space, and ornament are the same thing. The appearance of the subdivided gothic window, with its arches, flower motifs, and other decorative elements is also the structural answer that allows the proper distribution of loads and also function as the architectural and expressive elements of the building. Today, we again see the use of structure as part of the building language and discover the beauty of non-linear systems (Hwang et al, 2006b, p. 70).

Now completed and operating, the building, with its physics, biology and cultural significance realised, is 'just an Olympian test of theoretical physics ... [an] experiment that thinks it's a swimming pool' (Rogers, 2004).[13]

In summary, we have now identified the following features of contemporary architectural designing:

1. In a poor rural area, the humanitarian designing of the METI School saw architects working with the local community to interpret its educational views in a building that used renewable materials in creative ways, thereby developing heterogeneous spaces tuned and responsive to the children it serves.
2. Aspiring to be a sustainable urban skyscraper, the designing of 30 St Mary Axe was opportunistic with respect to the generative capacities of its environment: it begins to blur the boundaries between building and environment, merging both as one continuous ecology (Furján, 2007).
3. Standing as a groundbreaking iconic venue, ideas for the Beijing National Aquatic Centre emerged serendipitously during the early collaborative designing from such disciplines as biology and physics and these were selected on cultural and architectural criteria to generate a novel, complex, material system.

We are now in a position to set these features of contemporary architectural designing alongside a cutting edge view of learning. We briefly describe that view first.

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[12] Currently, researchers are investigating questions related to the interaction between material, structure and environment, asking: 'Is it possible to fundamentally rethink architecture – not as a mere change of appearances, but, instead starting from the relevant parameters that regulate the generation and behaviour of the built environment? What could be the starting point for this and which examples might guide this effort? ... Central to this research and the related studies are material systems that interact with a context-specific environment and that respond to structural, functional and performative criteria' (Arch+, 2008).

[13] Beyond the Watercube, Drenckhan and Weaire (2004) make a call for the testing of other structures derived from nature and understood through theoretical physics in terms of their utility for architectural design:

> This building has a wonderfully ingenious and complex construction, but still within the overall constraint of a rectangular building, which perhaps reflects the necessary form of its principal swimming pool. Future buildings, however, are likely to combine intriguing internal structures with more expressive external forms. In this process, scientists should not stand back and admire (or condemn) such designs, but offer inspiration, suggestions and directions. Fractals, quasicrystals, catastrophes, minimal forms ... Our repertoire is formidable, and remains to be exploited! (p. 4).

Generative Learning: Exploring Synergies with Architectural Designing

A generative theory of learning (Schaverien and Cosgrove, 1999, 2000) is derived from biopsychology and evolutionary epistemology (Plotkin, 1994, 1997) and neuroscience (Edelman, 1992, 1993). On this view, learning (or knowledge-gaining) is conceived biologically, as an adaptive behaviour (after Edelman, 1992, 1993 and Plotkin, 1994, 1997, 2002, 2004) that hedges our chances of survival. According to Edelman (1993), 'To survive in its econiche, an organism must either inherit or create criteria that enable it to partition the world into perceptual categories according to its adaptive needs' (p. 115). Further, such learning (as adaptation) is evident at three nested levels (after Edelman, 1992, 1993 and Plotkin, 1994, 1997, 2002, 2004):

1. genetic – in genes by natural selection,
2. individual – in organ systems (immune systems and brains) over a life span of experiences, and
3. cultural – in groups by collective or cultural (including disciplinary) growth.

In essence, this is a view of learning as selection: as iterative cycles of generating ideas, testing them on their value and keeping those that survive these tests. It does not propose a biological analogy for learning: it accepts that learning *is* biological (Plotkin, 2007).

From this understanding of learning as selection, three central characteristics of learning have been distilled (Schaverien and Cosgrove, 1999, 2000):

- *Learning is driven by values.* In other words, learners' values play a central role: ideas that align with them survive, those that do not are discarded. From this account, we can begin to understand diverse, changing conceptions and ideas: Edelman (1992) states, 'We categorize on value' (p. 163) and Sacks (1999) elaborates how it is up to the learning organism to 'create its own categories and to use them to make sense of, to *construct*, a world ... its *own* world, a world constituted from the first by personal meaning and reference' (p. 61). This categorisation or selection is a mechanism for learning, the means by which learning occurs on a wash of evolving and evolved values to result in adaptive fit (Edelman, 1992, 2004).
- *Learning is a process of generating and testing on these values.* A selectionist (g-t-r) mechanism of generate (g) – test on value (t) – regenerate (r) operates. This view of learning contrasts markedly with earlier instructionist ideas of learning as transmission or absorption. Instructionism cannot account for innovation. To produce 'novel solutions to the problems posed by change – solutions that are not directly given in the experienced world' requires a selectional mechanism (Plotkin, 1994, p. 172).
- *Learning is developmental.* Such development is unique for individual learners and is epigenetic, determined in real time by possibilities emergent from learners' actions in each g-t-r cycle. Plotkin (1994) describes this development holistically: 'each individual is, in a real sense, created anew, the unique outcome of an immensely complex series of interactions between the different parts ... of that individual; and also between its genes, its developing parts and its environment. Epigenesis is the word used to describe this complicated, integrated, dynamic and probabilistic process of development' (p. 122).

These three characteristics provide a framework in terms of which to examine the nature of architectural designing as we have portrayed it in the three contemporary cases above. We can now investigate whether or not a synergy exists between Education (as generative learning) and architectural designing by asking three questions:

- *How central is the role of valuing?* For Heringer and Roswag, the identity and self-confidence of the community were paramount in their designing of the METI School. They recognised that such underpinning values could lead to long term self-sufficiency and a local aesthetic through the creative use of this village's abundant, renewable resources. Heringer's designing diary, too, is a testament to her own observations and valuing of particular spaces for children – and such heterogeneous spaces are now evident in operation (Heringer, 2008; METI School, 2008). Foster and Partners value workplace office environments where social interaction is integral, and this prompted the development of a plaza in 30 St Mary Axe, overlooking terraces in the atria, open design office spaces, and spectacular social floors on the building-top. The designing team constrained their exploration of innovation for the Watercube by adopting the culturally significant square geometry to explore how contemporary innovation might occur technologically.
- *Is there evidence of generating and testing on value?* When 'eventually, Dipshikha yielded to the irrefutable argument that the guiding principle of their development work – which is to recognise and develop locally available potential – should also be applied to the making of the (METI) school' (Aga Khan Award for Architecture, 2007, p. 149) the architects put the new mud and straw technique ('Weller') and bamboo construction to tests which were analysed to ascertain the qualities of these materials. The res-

ults of these tests led to modifications in the construction techniques (see Photos of Realisation, METI School, 2008). When Foster and Partners explored how a skyscraper might sit on the site (previously consumed by the Baltic Exchange) they perceived that a circular building would enable new public spaces and pleasant communal areas (see animation of these potential skyscraper forms, Foster, 2007). When the cross-cultural designing team selected a square form for the Beijing National Aquatic Centre proposal, they realised that in order to win this design competition they would subsequently need to innovate on another level, structurally, which led them to generate and test ideas from biology and physics.

- *Can we characterise progression epigenetically?* In Heringer's designing of the METI School we witness a fortuitous process unfold over time: 'The school is the fortunate result of a chain of events that began in 1997' (Aga Khan Award for Architecture, 2007, p. 149; such events are documented by METI School, 2008). The designing of 30 St Mary Axe developed from ideas seeded decades earlier (Climatroffice), ideas realised when new technologies such as parametric modelling made it possible to deal with the complexity and diversity. As the proposed design for 30 St Mary Axe evolved, the Corporation of London planners and the Royal Fine Art Commission considered how it appeared on the skyline, aesthetically ('there was a dumpiness about the proportions'), and provided suggestions that Foster and Partners used to refine the building's form (Powell, 2006, pp. 69, 72; von Arx, 2006b). In the team's early designing of the Beijing National Aquatic Centre, the form, material and structure were generated and tested on value in turn, when a novel shift emerged and an ingenious complex material system was conceived that integrated these three components.

We recognise various constraints and limitations to such archival case accounts of architectural designing as we have described. For example:

- The literature provides a fragmented record of designing development over time and therefore gaps in particular detail may appear. The resulting snapshots of what is described or deemed to be of importance may lock into a particular interpretation and so risk giving an impoverished view of architectural designing.
- Accounts might be written retrospectively thereby neglecting possibly significant fine-grained detail as it is occurring, or failing to give a chronologically accurate record, and at worst, risking a different story being written.
- The discourse of professional architectural designing might mask the struggle that such human activity encompasses and instead emphasise particular successes or failures as end points.

However, despite these limitations, the presence of all three of these key characteristics in architectural designing in the three cases is strongly suggestive of a theoretical synergy between architectural designing and learning – and hence Education.

How might we test whether such synergy actually plays out in operation? One way could be to choose some contexts that blend architectural designing and learning and see whether we can detect, in the composite itself, those key characteristics we now speculate that architectural designing and learning share (namely, a central role for valuing, the presence of generating and testing behaviour and developmental progression over time). The first author's doctoral study[14] provided three such contexts.

Learning to Design

First, a study sought to gain insights into designing through learning to design. The first author became a researcher-as-learner, participating as a student in an undergraduate subject (*Architectural Design: Design Basics)* in the Faculty of Design, Architecture and Building at her university and documenting this learning as an autobiographical case study. From our preliminary analysis of findings thus far, the following evidence of the three key characteristics identified has emerged:

- When students generated their three initial design ideas from a client brief in the studio project, the architect-tutor explored which principles might be driving each unique idea. As well, he provoked students to recognise the significance of such (architectural design) principles for guiding their subsequent designing decisions, and how such values could inform the development of students' ideas (for example, Golja and Schaverien, 2007a, p. 141). Ideas that were primarily plan- or function-based were not highly regarded or perceived as viable, suggesting the operation of a powerful hierarchy of design values (Golja and Schaverien, 2007a, p. 137).
- The students in the studio produced quite different design ideas from essentially the same client

[14] We have already reported elsewhere some early findings of the first weeks of this author's learner-researcher investigation into her own learning to design, in a community of students also learning to design, in a studio-based undergraduate architectural design subject (Golja and Schaverien, 2007a, 2007b).

brief. From that early designing, at least two instances of generating and testing on value are evident: (1) where there were similarities of design (for example, three elements – as 'fingers', as elements tumbling down a hill (Golja and Schaverien, 2007a, p. 137)) it appears that students were identifying, interpreting and testing a particular value, and; (2) then, 'once the principles underpinning students' different design ideas were made explicit, it was up to each student to use them to develop their idea (now a concept) and in the process, to test the worth of their particular principles' (Golja and Schaverien, 2007a, p. 141). Clearly, students were not only generating and testing their design ideas on the values of their client (Golja and Schaverien, 2007b, pp. 3-4), the architectural design field (Golja and Schaverien, 2007a, p. 141), and their own personal values (Golja and Schaverien, 2007a, p. 134). They were also provoked to test the particular values they had selected to build into their design ideas for their utility.

- The architect-tutor's provocative question – 'How come the person next door to you, you're working from essentially the same brief, produces or ends up designing quite different things?' (Golja and Schaverien, 2007b, p. 5) – highlighted the developmental character of the designing that occurred. We have already described how the brief seemed to provide 'a starting point and a set of constraints for the designer who comes to this designing with his or her own unique history, experiences, agendas and architectural expertise' (Golja and Schaverien, 2007b, p. 5). The first author's account of her first four weeks of learning to design (Golja and Schaverien, 2007a) reveals the complex interactions of such development. For example, she used her personal experiences of the site location to list its environmental characteristics, exploring how these might shape the designing (pp. 134, 133 – Week 1). She modelled, using plasticine, to generate a range of ideas, and settled on one with a hole in its form that would bring nature into the building itself (pp. 135, 133 – Week 2). She contemplated the diverse student designs in this studio learning community, questioning what might enable or hinder such development and what architectural principles could now progress her designing ideas (pp. 136-7, 141 – Week 3). Then, when her own designing faltered, in the studio she was privy to the architect-tutor's feedback on another student's design idea showing how the powerful use of a particular medium (computer technology) could advance his designing – and she recognised how her medium (plasticine) now restrained any further development of her design idea (pp. 138-140, 141 – Week 4). Much later, after completion of the subject, when the first author conducted a series of sustained conversations with four fellow students, they reported how their particular individual and unique histories, experiences, agendas and architectural expertise and their various interactions within the studio had shaped the development of their designs, dynamically, over the course of that one semester.

Of course, these three examples alone cannot confirm, in practice, a stable synergy between learning and architectural designing, though such preliminary findings as these allow us to speculate that such a synergy might well exist. Analysis of the findings of this learner-researcher's study of learning to design is continuing; and two other contexts give further weight to our speculation.

Teaching Design

The first author conducted a second study of teaching students to design. She worked as an academic developer-researcher alongside an architectural design academic responsible for teaching a postgraduate studio-based digital architectural design subject (Golja and Schaverien, 2007c). Over a six-month period, the first author collected data primarily in audio and video form as a developmental record of the subject. She attended most of the teaching sessions, audio- and video-recording the teaching and learning interactions as they occurred (although there were serendipitous meetings between teacher and students in the lab when she was not present). As well, using a conversational methodology (Cosgrove and Schaverien, 1996; Golja and Schaverien, 2005) she explored the teaching academic's planning, conduct and development of the subject, prior to and concurrently with its offering; and she conducted focus groups with students so as to elicit multiple perspectives on their learning experiences of the subject over time. Our analysis of this teaching is in its early stages. However, its subject outline descriptions of its three central projects (Inorganic Life, Active Systems and Inter_Action Space) reveals the following signs of generativity:

- Project 1 (Inorganic Life) invites students' generative consideration of: 'Quantum physics is generating an understanding of nature as a series of energy fields. Objects are seen as manifestations of internal and external conditions that distort and shape matter and energy into a perceivable form. These objects are always in flux and only 'appear' stagnant to the human eye. We will start this semester with the re-examination of design as a condition of stasis and not statics' (Hatzellis, 2006).

- Their first project asks students to investigate the dynamic ways in which material systems (in this case, tensegrity and minimal surfaces) might respond to different data sets and could be modelled using digital techniques and technologies: in other words, to 'experiment with computational devices that allow for new forms of architectural interfaces and spaces to emerge' (Hatzellis, 2006).[15] Opportunities for such work to be tested were also evident: for example, students presented their ideas for feedback to panels of invited jurors (professional architects), and published their research and findings to enable further investigation.
- This series of three theme-based projects, each introduced in a workshop, explicitly set out to be developmental: 'These workshops are sequential, with the research in the earlier workshops being carried forward to the later' (Hatzellis, 2006).

Further analysis of this study's data set will provide a clearer picture of whether or not architectural design teaching embodies those key characteristics (of a central role for valuing, the presence of generating and testing behaviour and developmental progression). Meanwhile, we conclude our paper with speculative consideration of a third context for evidence of these three key features.

Researching Architectural Design Education

The first author's first study (of learning to design as a learner researcher), together with a consideration of three contemporary cases of mature but innovative architectural designing, yielded a set of testable ideas about the nature of architectural designing. Her second study (of teaching architectural designing, conducted as an academic developer researcher alongside the responsible academic) put these ideas to a test, with a view to understanding whether and if so how educational design might be manifest in this context. We hope that the results of this research test will provide an answer to the question of whether and if so in what respects, at least in the field of Architectural Design Education, Education can be considered to be a designing discipline (Golja and Schaverien, 2007c).

This paper represents an important step towards an affirmative answer to this question by describing early indications of a theoretical and operational synergy between Architectural Design and Education (including learning, teaching and researching). Such a synergy may well provide (generative) language and principles needed for architectural design lecturers to sharpen and refine their aspirations for their students in their teaching. For example, particular aspirations for subject components, courses and/or programs could be re-described, examined and/or evaluated generatively, identifying specific ways in which generative learning and teaching approaches might (or might not) play out within those broad brush features that the present examination of this synergy has been able to reveal.

Of course, it is too early to say for certain whether the investigated synergy will be found to hold or, following from that, whether or in what senses Education will be found to be a designing discipline, although there are some positive indications, as described in this paper. In any event, the research promise of a clearly theorised Architectural Design Education will no doubt be a truly generative outcome.

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[15] Earlier explorations of tensegrity had been undertaken by Buckminster Fuller, and in the case of minimal surfaces, Frei Otto had devised soap-film experiments. The students were required to extend such explorations using new technologies and techniques now available.

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Tanja Golja is a doctoral student in the Faculty of Arts and Social Sciences, researching the fruitfulness for Education of the concept of design. As part of her responsibility as an academic developer within the Institute for Interactive Media and Learning, she works closely with academic staff in the Faculty of Design, Architecture and Building, collaboratively seeking to enhance the Faculty's design and successful provision of rich learning opportunities for students within the designing disciplines. As a graduate of the foundation cohort of the Master's degree in e-learning, Tanja takes a special interest in technological ways of gaining insights into the educational ideas and practices of different disciplines, for the learning benefits of students and the wider culture. Currently, such collaborative investigations are exploring how to build and sustain imaginative, research-based technological learning environments.

Dr. Lynette Schaverien

Associate Professor Schaverien is an active researcher in science and technology education, with a special interest in understanding the design of theoretically sound e-learning environments in a range of disciplines. In recent years, she has led two sizeable and successful Australian Research Council projects in which students and teachers respectively have designed acclaimed and radically innovative e-learning environments in which others can engage with scientific, technological and educational questions of high interest to them. In both these projects, designing and learning to design are of key interest at two levels: in participants' shaping of the environments themselves and in researchers' enactment of a research process to nurture and understand it. She has also led the design, development and teaching of a market-leading suite of postgraduate e-learning courses, in collaboration with her university's Institute for Interactive Media and Learning.