Bio inspired Intelligent Design for the Future of Buildings

Gilder, J.
University of Reading, UK.
Clements-croome, D. J.
University of Reading, UK.

Abstract

In ‘Architellect’, the current world of Intelligent Architecture (subset of ID), effectiveness and applicability are the keywords in a flexible design. One can achieve an intelligent-flexible design by enveloping a built form through the extremities of outside by harnessing, storing, character changing and engineering.

During my post-graduation in ‘Intelligent Buildings’ at the University of Reading, my thesis was a compilation of design proposals for using smart technologies and contemporary materials to supersede the old age practice of brick, stone, lime and mortar.

Most design solutions presented in this privately sponsored research were inspirations from the efficiency and refinement seen in nature and the principles were not confined by location or weather.

**Project Setup:** The above research aimed to design a building for demonstrating a radical design approach in response to changing financial scenarios, technological developments and modern ways of working. One major challenge included the analysis of building design, thereby understanding the inherent characteristics and highlighting the advantages / disadvantages of the project. The opinions of prominent practitioners in the fields of Architecture, Sustainability, Engineering, and Finance, were gathered by floating a DQI (Design Quality Indicator).

The questions that were chosen highlighted what they thought to be the important parameters in present global terms and in future designs and systems. The DQI brought out the means to assess what aspects of the buildings current design should be further looked and researched into.

Perceiving the future, it was concluded that further research into the engineering of smart materials and technologies was essential since it could be the next wave in the future of architecture.

**Keywords:** flexible design, innovative materials, bio-mimetic, dynamic and cognitive, smart components and systems
1. Intelligent design

1.1 The theory of intelligent design (ID)

The theory of intelligent design (ID) holds that certain features of the universe and of living things are best explained by an intelligent cause rather than an undirected process such as natural selection (Discovery Institute. 2007). ID is a scientific disagreement with a core claim of evolutionary theory that the apparent design of living systems is an illusion.

In a broader sense, Intelligent Design is simply the science of design detection -- how to recognize patterns arranged by an intelligent cause for a purpose. Design detection is used in a number of scientific fields, including anthropology, forensic sciences that seek to explain the cause of events such as a death or fire, cryptanalysis and the search for extraterrestrial intelligence (SETI). An inference that certain biological information may be the product of an intelligent cause can be tested or evaluated in the same manner as scientist’s daily test for design in other sciences.

Understanding the above and also realising that science is provisional and is subjective to many influencing parameters, we branch out from this point into the world of Architectural Design and try and understand the disparity pronounced in the design created by man against that of nature. The built form as an artefact of the human conscience has been metamorphosed for underpinning various statements. Its evolution has been laying the benchmark in parallel to man’s evolution. The understanding and engineering of buildings, has been an attempt to make them as human sensitive and human responsive as possible with prevalent technology and systems. The empirical science known to man is provisional by nature and so is the definition of the Intelligent Building been time bound by the varying developments in science and technology.

*Intelligent Design in the manmade realm could be viewed as dynamic organisms, which have and are evolving with the progress of Humans within a sustainable Environment.*

In the current world of Intelligent Architecture (ArchitEllect), the much spoken word around is the initiation and application of flexible design which can envelope a built form through the extremities of outside by harnessing / storing / character changing and engineering. The fundamental aim for any habitable design is the need to create a working micro environment. A building needs to be looked upon as living organisms that harbour its inhabitants from the external.

Most of the design solutions attempted in this research shall be inspirations from efficient and refined nature and the principles shall not be confined by location or weather.
2. The project – (submitted to a panel of referees, for undertaking research on the feasibility / possibility and viability of bio-inspired intelligent designs in the future)

2.1 Introduction

We tend to house people into buildings, personalize their ambient conditioning and expect them to perform in that particular environment. However, not all jobs and task can be done in such ways. Research has shown that people perform at their best when they are in a state of psychological and physiological comfort; in places which provide them with the right frame of mind to be in.

In present times, the skill and creativity of the human mind is of utmost value in a knowledge based economy. More and more design studios, classrooms, discussion and meeting based businesses are designed for nurturing valued individuals. Such designs, call for personalized volumes and spaces which could be variable customized in every aspect.

Another aspect of our current civilization that is rapidly changing is our working culture. The metamorphoses between working and living spaces are bringing them together as one. A survey conducted in the early 1990’s in Britain showed that approximately 4% of the working population worked full time from home. That figure is now 12% and is expected to be 20% by 2010. This fundamental change eliminates:

1. The need to travel – saving time, energy, money and in most cases fuel.

2. The need for a secondary infrastructure.

We tap on this rapid change never the less knowing that there shall always be an intimate social need for congregation periodically. Such periodical gatherings shall require social spaces and volumes rather than a dedicated workplace. It must be adaptive and responsive to variable conditions, situations and occasions.

Accepting the certain, and the change brought about by economic drivers, we must now realize that the offices and commercial buildings of today will soon become a liability of tomorrow (the near future), as soon as commercial enterprises start leasing out spaces for gatherings of people rather than corporate bodies having dedicated buildings to house their soon to be virtual staff.

For the purpose on this research we undertake a project whereby, we need to build one such congregating space that is to be leased out for variable periods of time. The financial feasibility of such high spec intelligent spaces are now justifiable as the lease would be of a high margin considering that corporate bodies will be willing to pay higher prices for short periods of time, rather than having dedicated buildings.
ADVANTAGES:

1. **Minimization of infrastructure** - less buildings – less energy – less carbon.

2. **Less travel** – saving time, energy and fuel and cost - less carbon.

3. **Corporate offices now maintain virtual working environments** rather than the physical- less cost – less maintenance – less carbon.

4. **Intelligent and high spec quality buildings** leased out for periodical gatherings at a higher lease rate become a feasible, viable and enjoyable lifestyle option.

![Figure 2.1: Membrane structures provide the flexible and adaptive properties that we seek for in the next wave of intelligent buildings](image)

The Envelopes for such built forms could be of membrane structures (fig.2.1) with electronically controlled BMS systems for lighting, energy consumption, and heat and transmission indices. Interoperable and open node cells for personalized needs and displays. This shall inform and keep a track of energy needs and waste disposals. Such an interconnected matrix of electronic nodes could be the future of intelligent buildings.

### 2.2 Material selection for the project

*Smart materials are often considered to be a logical extension of the trajectory in materials development towards a more selective and specialized performance (Addington, M. and Schodek, D. 2006).* For many centuries one had to accept and work with the properties of standard materials such as wood or stone, designing to accommodate the material's limitations, whereas during the 20th century one could begin to select or engineer the properties of a high performance material to meet a specifically defined need. *Smart materials allow even a further specificity - their properties are*
changeable and thus responsive to transient needs. For example, photochromic materials change their color (the property of spectral transmissivity) when exposed to light: the more intense the incident light the darker the surface (Askeland, Donald R.; Pradeep P. Phulé 2005).

The ability to respond to multi states rather than being optimized for a single state, gave smart materials a distinct advantage on the designers table since buildings are always confronted with changing environmental conditions. As a result, we are beginning to see more proposals on the usage of smart materials and how they could replace more conventional building materials.

Cost limitations and availability has always been the road block to product / material launch. The replacement process of new from old tends to occur through high visible showpieces (such as thermochromic chair backs, an electrochromic toilet stall doors) and later through big profile 'demonstration' projects such as Diller and Scofidio’ Brasserie Restaurant on the ground floor of Mies van d Rohe’s seminal Seagram’s Building. [Addington, M. and Schodek, D. 2006]

Material Science shows that smartness in a material or system is determined by one or two mechanisms, which can be applied directly to a singular material, and conceptually to a compound system. If the mechanism affects the internal energy of the material by altering either the material’s molecular structure or microstructure then the input results in a property change of the material.

Addington, M. et al. 2006, further confirm that the properties of a material may be either intrinsic or extrinsic. Intrinsic properties are dependent on the internal structure and composition of the material. Many chemical, mechanical, electrical, magnetic and thermal properties of a material are normally intrinsic to it. Extrinsic properties are dependent on other factors. The color of a material, for example, is dependent on the nature of the external incident light as well as the micro-structure of the material exposed to the light. However, if the mechanism changes the energy state of the material, but does not alter the material per se, then the input results in an exchange of energy from one form to another.

Askeland, D. R. et al. 2005, have described a simple way of differentiating between the two mechanisms i.e. the property changes type (hereafter defined as Type I), the material absorbs the input energy and undergoes a change; whereas for the energy exchange type (Type II), the material stays the same but the energy undergoes a change.

As part of the research, many building materials for the architect were enumerated. A few illustrations have herewith been mentioned that were applicable to this project. Three dominant materials have been selected to be engineered for the larger parts of the structure. The two domes prominent in the upper floors of the structure (architectural drawings shown in figure 2.4) are conceived to be enveloped with type 1 and type 2 materials respectively, whereas the semi-open space is partially covered with tensile fabric units.

Fig 2.2, images 1, 2 and 3 shows the plan, view and elevation of a curved surface in direct sunlight and the variability of the surface area with respect to heat and incident sun rays.
2.2.1 Type 1: Photochromic Film Coated Membrane

Fig 2.2: Images 1, 2 and 3 show the plan, view and elevation of a curved surface in direct sunlight and the variability of the surface area with respect to heat and incident sun rays

Photochromic materials change colours when subjected to light. Many photochromic films are available that change from a clear state to a transparent colored state. These polymeric films can be relatively inexpensive as compared to photochromic glasses [Addington, M. et al. 2006]. Also the isolated layering in segments over the membrane allow for differential colour effects over a single homogenous membrane unit eliminating the need for any artificial ornamentation for façade treatments. The attached diagram (fig. 2.2), demonstrates the variable shading and colour changing possibility over a single surface. The main advantage of this being, that the transparency of the
membrane is not affected in the zone that is away from the sun. Also this action being voluntary with the cycle of the sun, negates the need for any controlling and sensory device altogether. However, in cases where the need arises for a controllable transparent membrane, the application of an electrochromic (potential difference) or chemochromic (chemical concentration) film over the same membrane achieves a user controllable skin.

2.2.2 Type 2: Photovoltaic cells embedded over Thermoluminescent membrane

An inspiration derived from the eye of a moth. Nature at work has devised a surface which is capable of absorbing 100% of the incident light rays towards it. A similar application is what a compact disc (CD) works on. A schematic diagram attached in fig.2.3, shows its working. The Photovoltaic cells mounted upon the membrane absorbs all incident sun rays from any global direction at any time of the year without the need for any manual or automatic override. The diagram depicts how the incoming rays once entered into the cells are reflected within the cell to the photovoltaic molecules around the surface of the sphere such that none leave the cell again. This absorption happens all year round in variable conditions generating the potential difference for electricity generation. Besides, the pattern developed between the opaque photovoltaic cell and the transparent membrane, gives the interior a frit glass envelope effect.
Fig 2.3. In order, from the top:

- A cross sectional sketch of the proposed photovoltaic cell over the membrane absorbing sunrays from all directions.

- Derived inspiration – the eye structure of the moth.

- Microscopic view of a schematic membrane with impregnations on its outer surface created for increasing its exposed surface area.

2.2.3 Property changing fabrics (thermochromic and photochromic cloths)

The second class of smart fabrics contains those that exhibit some form of property change when subjected to an external stimulus (Addington, M. et al. 2006). This class of fabrics are typically traditional fabrics that are either impregnated with thermochromic or photochromic material in dye form, or are layered with similar materials in the form of coatings or paints (Addington, M. et al. 2006). A similar concept is also the principal behind the form and enveloping skin for the auditorium (see attached architectural sections and elevations in figure 2.4). The ambience created by this translucent and transparent effect, compounded by the colour changing environment is envisaged to be stimulating for the inhabitants.
Fig 2.4: Drawings above show the architectural images of the envisioned structure.
3. Installing intelligent systems into the building

With the advent of technology, our buildings today are getting more and more responsive to human needs. Not only are the devices (automation / sensory based) making them easier to use and function, but also giving contemporary architecture an image of sophistication and high-tech look. We look at some of these systems that have been envisioned for this project:

3.1 BAS (Building Automation System)

The use of web-enabled devices, for the building automation system, which allows remote building control and monitoring by interaction of the central BAS workstation with the remote dial-up system via modem.

3.2 Embedded Sensors and Actuators

Figure 3.1: Fibre optic sensor embedded in composite structural element

Within the structure of the membrane skin, embedded sensors and actuators work giving out wireless information to the BAS system about user occupancy, heating and ventilation, security, etc. Attached figure 3.1 shows one such cross section of a membrane structure with an embedded sensor.

3.3 Integrating Structure and HVAC (Heating, Ventilation and Air Conditioning)

Computer vision system allows counting the number of residents within an air-conditioned space and informs the control system of the distribution of the residents. Internet-based HVAC system, allows authorized users to keep close contact with the BAS, wherever the user is. However, integrating the two brings an entire paradigm shift in the intelligent working of a building as explained below.

The base material chosen for this project is a high strength membrane concrete. Fluid in its form; within which is an entire network of heating and ventilation system, channelized to every part of the building. As shown in the attached figures (Fig. 3.2), the branching of the columns into the floor
beams and eventually the floor plate is an inspiration from the branching systems in nature (cross section of a human brain, the intestines of a dog, branching of tress, etc). Fig.3.3, demonstrates the optimum refinement in maintaining the least amount of pressure within a branching system to deliver material from one point to many. The analogy applies to the building whereby the chill water system for cooling or the hot water supply is carried through the fluid-form structure, just like the branches of a tree from the service areas to all parts of the building. This is another analogy, confirming on the metamorphosis of a built form to that of a living organism.

Fig 3.2: A virtual analysis of the model for this project showing the encapsulated routings of the heating and cooling network within the base material of the structure.
Fig 3.3: Natures derivation of the most optimum channelization route of evenly distributing pressure to all parts
4. DQI (Design Quality Indicator) results

4.1 Project setup

Respondents were told that the building is an exercise to demonstrate the radical design approach in response to the changing financial scenarios, technological developments and modern ways of working. It was circulated to receive their valuable comments on the possibility and viability of such endeavours in the near future. The questions that were chosen were peculiar to highlight what they thought to be the important parameters in present global terms and in future designs and systems. The DQI will be used as a means to assess what aspects of the buildings current design should be further looked and researched into.

Fig 4.1: Average section scores

Keeping in mind that this was a design exercise, the respondents have given maximum weightage on the performance of the project. The usage of smart and intelligent design materials and their engineering, promises to yield more from such buildings in terms of its effectiveness on the occupants. The improved internal cells and external ‘frozen clouds’ were concepts that were well accepted. However, there also seemed to be a lot of apprehensions on the practicality and technicality of the chosen concept.

The theory appeals in more ways than one, but its fruits are to be tested and analysed. This has been highlighted practically in every aspect by the respondents, verbally and in their written comments.
The Fig. 4.1 clearly depicts the outcomes of this exercise. It plots the relative average scores on a wheel circumferenced by the factors that were fundamental for the success of a new design approach. The respondents have shown a clear agreement with most of the questions that were asked in relation to the performance of project. They confirm and endorse the choice of material and spaces such envelopes create.

5. Conclusion - the design context in retrospect

The principles of Architecture and Design have been provisional to the times of technology and invention. We, as modern day designers and innovators in the coming generation of buildings have an unprecedented challenge in developing and engineering solutions which are flexible and adaptable with changing time and user. However, we learn through our mistakes and we must also look back at the History of Building Construction to remind ourselves of ‘our’ science being provisional and hence what we consider intelligent today will be rudimentary tomorrow. There is a common belief that technology is deterministic, i.e. that our tools determine our behaviour. Yet, oddly enough, the field of architecture is relatively immune to technological domination. This may well have benefits as well as the disadvantages that we have already pointed out about clinging to obsolete technologies long after the underlying science no longer supports them.

Keeping that in mind and perceiving the future, this paper makes an attempt to identify the next wave in architecture. The building industry has always been technologically driven. But that was until the recent awareness on the potential impact the industry has on the planets ‘web of life’ and is equally dependent on her resources. Our current energy, building and material models have been impoverishing the diversity of nature and this is a bold statement that we as a species have to own up to.

The following summarizes some of the lessons learnt in this research and some of the FUTURE STUDIES needed:

1. Buildings are no more meant to be singular or fixed bodies but have to be understood as complex energy and material systems that are a part of the environment of other active systems. Therefore, it is imperative that future studies and research are carried out in the fields of artificial intelligence, information technology, economics, climatic study, material science, environmental engineering and biomimetic engineering.

2. The project has been built on the assumption and readings of the future economy. Thus consequentially leading to an evolution of spaces and envelopes that would address a new working environment. Considering the current built environment available, it would be interesting to take this study further to develop innovative skins for existing buildings that looks into issues of energy efficiency, mitigating the effect of climate change leading to a low carbon footprint.

3. The architecture is conceived, designed and proposed, on the foundations of embedded techniques and technology that may need to come together holistically for the future artefact. However, careful
considerations and **studies have to be made on the adaptability and qualitative characteristics of these technologies** to ensure not only user comfort but also efficiency in performance of the envelope in response to the projected climatic changes in the future.

4. Thus, we see a potential gateway in the realm of Intelligent Designs for the future. Our understandings in science and technology today are bridging the gap between nature and man. This disparity is the consequence of man’s misinterpretation of his evolutionary stage and as the human race dwells into the twenty first century, we need to humble ourselves into the realities of the planet we share with all other species on PLANET EARTH.

**References**


