Intelligent Eco-Physiological Architecture: A Primer for a Sustainable Built Environment

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Abstract

The art and science of designing buildings, architectural process, has evolved to the present philosophy that, with exception to ‘exemplar green buildings’, treats the building physiology as an isolated entity. Often referred to as a ‘black box’ or ‘bolt-on’ technology, ultimately with this ‘inside-the-box thinking’, the heating, cooling and lighting requirements of the occupants are designed relative to and not with the building design. This conventional design philosophy is to first provide a functional space which meets psychological and cultural/local vernacular/aesthetic precedents at the building design stage and then to consider options for meeting the physiological needs of heating, ventilation, air conditioning (commonly referred to as ‘HVAC’ systems) and lighting, met using equipment at the ‘fit out’ stage meet. The fundamental principle of a revived ancient design philosophy is investigated in this paper, that of intelligent homeostatic Integrated Architecture, which treats physiological design also into building form, fabric, and aesthetic: True Architecture. This ‘outside-the-box’ paradigm is necessary to achieve a sustainable built environment through state of art intelligent selfresponsive ventilation, thermal storage, and daylighting. The process is brought to a new level further through integrating the building design with ecological features which serve to enhance performance and sustainability through free-cooling, filtration, oxygenation, carbon sequestration, whilst promoting bio-diversity and considering a whole life cycle approach to create a new vernacular: Eco-physiological Architecture. This paper presents a methodology for achieving an Intelligent Eco-physiologically neutral architectural solution with reference to three case study buildings submitted for planning application in Ireland. The complete design approach comprising the conceptual stage, performance and parametric analysis, to final integrated detailed design team stage for planning application is surmised and recommendations inferred to serve as a primer for Intelligent Ecophysiological Architecture.

Keywords: design methodology for eco-physiological architecture, advanced natural ventilation, underground thermal energy storage, building integrated flora, sustainable building design.
1. Background

Ancient architecture established the precedent for sustainable design through the use of daylight, sun, night air, and natural ventilation. Courtyards, gardens, water features, large high spaces with high level windows, large thermal massive structures, combined to form a vernacular that provided thermal and visual comfort. Across Egypt and the Middle East the form was developed further to establish consistent ventilation provision through use of stack effects and when available wind: the wind scoop (Malkaf) for admitting or exhausting air to the space and the multi-shaft variant therefore (Badgir), which provide bi-directional air flow to and from the space. Fathy (1986) re-established the ancient vernacular of Egypt with particular reference to ventilation physiological elements and the use of integrated evaporative cooling to avail of the hot arid climate. Where additional cooling was required, large underground chambers were formed, in which large thermal mass was placed for subsequent cooling using night air admitted through underground shafts that led to thermal reservoirs prior to low level delivery to the occupied space, induced by the exhaust stacks. Figure 1 illustrates in summary, the most prominent ancient technology evolution, that of Ancient Egypt.

Considering the impending global warming pandemic and associated worsening weather conditions, our associated carbon reducing and energy performance commitments (by way of the Energy Performance in Buildings Directive Building Energy Rating standards for each state), the imminent intra-generational equity of the built environment and associated carbon production, and most tangible to most, carbon taxes (now confirmed for Ireland), it is paramount that a paradigm shift in architectural design toward a new sustainable vernacular is adopted in earnest. A dichotomy exists in conventional architecture between the general philosophy and physiology of architecture as set out in Figure 2 and needs to be crystallized into a more congruent holistic entity that reflects on the fundamental design principles developed in the past to yield a consistent sustainable design in the future. The building is proposed as a self-sustaining integrated system of core physiological functions within which an emotional environment is generated from a holistic architectural design as illustrated by Figure 3.

2. Eco-physiological architecture: a sustainable vernacular

Considering the physiology of architecture, the science and art of building design as set out in the Vitruvian model (ca. 25 BC) and later immortalised though Di Vinci’s (ca. 1487) ‘Vitruvian man’ image is depicted in human physiological terms rather than the original geometrical paradigm. It is proposed that a building be considered anatomically comprising: i. the control centre or biologically, analogous to brain or brain function (BF) (Building Management System), ii. the energy centre, analogous to heart or heart function (HF) (core and renewable energy generation and distribution systems), iii. the ventilation system, analogous to lungs or lung function (LF), iv. the filtration systems, analogous to nostril for oxygen supply filtration or nostril function (NF) and liver, analogous to foul waste filtration or liver function (LVF), v. the natural light system, analogous to the eyes or eye function (EF), and vi. the outer shell, analogous to the skin or skin function (SF).
The epicentre is the brain which takes the form of a building management system, programmed to monitor and control all non-homeostatic functions to ensure human physiological comfort, whilst sustaining all of the floral mass used throughout the building and surrounding site, daylight linked lighting, night cooling, weather compensated heating control, renewable and core energy systems, and ancillary functions (security, emergency service link, auto fuel ordering etc.). The heart, located central to the form, connected to a floral mass of type most efficient for evapotranspiration to provide pre-cooling in summer and shelter from winds in winter, equally distributes all energy flows (heating, cooling, and electrical) throughout the building at optimum potential drop and related energy expenditure. The lungs, take the form of stacks distributed throughout the building to induce stack driven airflow independent of wind coupled with inlet air chambers integrated with floral mass of type most efficient to oxygenate incoming air. The nostrils take the form of floral mass surrounding all inlet ports to the building, of narrow leaf type most efficient to filter and decontaminate incoming air (pine species), and the Liver which takes the form of additional floral mass, of type most efficient at filtering foul or black water (Reed Beds) and broad leaf type most efficient to carbon sequester are located to provide independent sewage treatment prior to drainage to watercourse and carbon capture to the development. Finally the skin, takes the form of a super-insulated air tight shell encapsulating all the aforementioned functions, providing each with appropriate protection from undesirable ambient elements whilst elaborating the psychological story being conveyed through its form, style and finish.

Considering these building blocks, the building is assembled in so far as is practicable to form an holistic physiological solution which is in harmony with the prevailing general architectural philosophy for a given project. Table 1. summarises the parametric analysis of each physiological component from which a generic methodology for design which considers physiological parameters alone. Figure 4 illustrates the design methodology proposed to reach an integrated sustainable Eco-physiological Architectural solution and Figures 5 to 12 architectural inference diagrams to each anatomical analogy presented. Figure 13 illustrates how the core services or heart of such a development that comprises of four components can yield a net carbon neutral solution, which is further exemplified in this application to maintain human physiological comfort by Figure 14.

3. Eco-physiological architectural design: three case studies

The maritime climate of the British and Irish Isles is presented through three case studies: one located in the Irish Capital of Dublin and two along the Irish West Coast. The built environment typology spans a range of functions from a large city centre office block building (Dublin), a mixed mode retail, office, and residential development (West Coast) and a town centre mixed-use train station redevelopment (West Coast). The proceeding Figures illustrate the fundamental conceptual design sketches for each development highlighting the common thread of Intelligent Eco-physiological Architectural Design (IEPAD) which runs throughout.
3.1 Dublin City Office Block (Figure 16)

The core systems were selected for the city urban typology of Dublin to include solar thermal panels and vertical axis wind turbines and rainwater harvesting (LVF – through reduced surface water runoff) for water closets and floral watering. A heat pump that utilises ground water for primary heating and cooling function (HF). Thermal mass was exposed for thermal storage (HF) and a BMS (BF) configured to control the advanced natural ventilation and ancillary renewable energy systems used throughout to minimise operational core system energy demand. The Building typology (SF) is planer form of modern city vernacular adopting a centre in edge out (lung function, LF) optimum Eco-Integrated Advanced Natural Ventilation System with perimeter shrubs and broad leaf trees for maximum local shading and oxygenation (LF) and filtration (NF). The central atrium housed floral features for air filtration (NF) and oxygenation (LF). A mix-match approach of perimeter transparent ducts was integrated into the smooth planer façade such as not to affect the overall aesthetic whilst acknowledging the fundamental exhaust air route typology. Daylight (EF) was optimised through the narrow floor plates encapsulated by predominately-glazed facades to street and atria faces (DF). A highly insulated and airtight twin skin façade (LF) forms the building shell (SF). Figure 15 illustrates the architectural led proposal and Figure 16 a converged physiologically integrated solution.

3.2 A mixed use retail, office, residential development located on the Irish west coast (Figure 17)

The core systems were selected for the coastal Greenfield site typology of Western Ireland to include (HF) biomass thermal heating, solar thermal panels for domestic hot water, vertical axis wind turbines for electricity generation and rainwater harvesting (LVF) for water closets and floral watering. A heat pump utilises ground water for primary heating and cooling function (HF). Thermal mass was exposed for thermal storage coupled with underground supply air networks for pre-cooling effect (HF). A BMS (BF) is configured to control the advanced natural ventilation and ancillary renewable energy systems used throughout to minimize operational core system energy demand. The Building typology (SF) is planer form of modern vernacular adopting a network of centre in edge out Eco-Integrated Advanced Natural Ventilation Systems (LF) with shrubs and ferns/firs for maximum local filtration and oxygenation (LF, NF). Central elements comprise of air well atria (Figure 5) A mix-match approach of core area shafts modified to form solar stacks at roof level was integrated into the open plan layout such as not to affect the overall aesthetic whilst acknowledging the fundamental exhaust air route typology. Daylight (EF) was optimised through extensive light wells to form narrow floor plates encapsulated by predominately-glazed facades to street and atria faces. A highly insulated and airtight mixed twin/single (LF) skin façade forms the building shell (SF).
3.3 A town centre and train station re-development in Western Ireland (Figure 18)

The core systems (HF) were selected for the coastal town-centre site typology of Western Ireland to include biomass CHP thermal heating and electricity generation, solar thermal panels for domestic hot water, vertical axis wind turbines for electricity generation and rainwater harvesting (LVF) for water closets and floral watering. A heat pump utilises seawater (Atlantic Ocean) for primary heating and cooling function. The core in this case forms the heart of the development, which comprises several different buildings, is located at the centre thereof. Thermal mass was exposed for thermal storage coupled with underground supply air networks for pre-cooling effect. A BMS (BF) is configured to control the advanced natural ventilation (LF) and ancillary renewable energy systems (HF) used throughout to minimise operational core system energy demand. Each Building typology is of plastic form (SF) akin to maritime vernacular adopting a network of centre in edge out Eco-Integrated Advanced Natural Ventilation Systems (LF) with shrubs and ferns/firs for maximum local filtration (NF) and oxygenation (LF), all encapsulated by an ‘ETFE’ sail (SF). The sail covers all streets between buildings that are laid out as ecological corridors to bio-integrate with the existing townscape.

Central elements comprise of air well atria (LF) (Figure 5) and light wells (EF) (Figure 6) configured for low level air supply from the subterranean fresh air network. A mix-match approach of core area shafts modified to form solar stacks (LF) (Figure 7) at roof level was integrated into the open plan layout such as not to affect the overall aesthetic whilst acknowledging the fundamental exhaust air route typology. Daylight (EF) was optimized through extensive light wells and streetscapes to form narrow floor plates encapsulated by predominately-glazed facades to street and atria faces. Figure 19 and 20 illustrate the core and ventilation integrated elements, which converged to yield a physiologically integrated solution. A highly insulated and airtight mixed single/twin skin façade (LF) forms the building shell (SF).

4. Summary

A sustainable architectural design paradigm is presented: Intelligent Eco-physiological Architectural Design (IEPAD). The philosophy considers the building as a living form comprising the six fundamental human bio-functions: brain, heart, lungs, nostrils and liver, eyes, and skin. Architecture in its present form is often unsustainable, substituting psychological and related aesthetic ambition in favour of energy efficiency and performance. A design methodology is presented to guide the design team to the core building blocks of a sustainable design that establishes sustainable physiological design on an equal footing to traditional psychological, and therefore encourage an optimised building energy performance (A-rated BER), whilst acknowledging – if not enhancing the original architectural intent therein. Three case studies are presented and a sustainability critique for each surmised. Further research is required into the operational monitored performance of IEPAD systems in absence of available data for the maritime climate of Ireland and the design case studies presented.
5. Tables and Figures

Table 1. Physiological Architectural Parametric Analysis

<table>
<thead>
<tr>
<th>Physiological Function</th>
<th>Tissue</th>
<th>Core Distribution System</th>
<th>Environmental</th>
<th>Ventilation</th>
<th>Physiology</th>
<th>Design</th>
<th>Depiction</th>
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<td>Nervous system</td>
<td>Respiratory</td>
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<td>Heat dissipation</td>
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Figure 1: Evolution of Ancient Egyptian Architectural Physiology (Adapted from Khalil, 2008)
Figure 2: Dichotomy of conventional architecture

Figure 3: Sustainable Physiology Design Proposal
Figure 4: Eco-physiological Architectural Design methodology
Figure 5: Air Well-atrium
Figure 6: Light well with summer shade
Figure 7: Solar stack

Figure 8: Wind stack
Figure 9: Chimney/pipe/duct
Figure 10: Courtyard
Figure 11
Lattice integrated wall shafts

Figure 12
Supply and exhaust configurations (Lomas, 2007)

Figure 13
Core Systems Carbon Neutral Architecture
Figure 14 Carbon Neutral Human comfort in the built environment (Farrell, 2007)

Figure 15 Architectural proposal for Dublin Office Block (HKR Architects, 2009)
Figure 16 Eco-physiological Architectural Design solution highlighting perimeter solar stacks

Figure 17 IEPAD proposal for mixed-use development in Western Ireland (MMA, 2009)

Figure 18 A Town centre and train station re-development in Western Ireland (MMA, 2009)
Figure 19 Core systems for town centre redevelopment in Western Ireland (MMA, 2009)

Figure 20 Ventilation systems for town centre redevelopment in Western Ireland (MMA, 2009)
References

Di Vinci, L. (ca. 1487) *Canon of Proportions, Drawing and text stored in the Gallerie dell'Accademia in Venice*, Italy.


