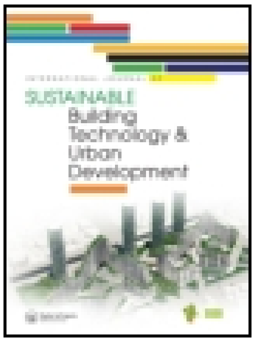

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Blind spots of sustainability: architecture

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ABSTRACT
The building sector has now reached the stage where numerous sustainability codes and practices have been introduced and enforced in an attempt to reduce carbon emissions associated with the built environment. While these efforts have been successful in shifting the industry towards more sustainable practices, they have had limited success in reducing the sector's total energy consumption and carbon emissions. This paper discusses how the intended purpose of architecture has contributed to this shortfall, and how it has obstructed the potential environmental benefits of emerging building technologies. It is argued that if the fundamental way in which buildings are designed remains unchanged then it is likely that the targets for reducing carbon emissions will not be met, and that an increase in these emissions will occur. The paper also provides insights into how these shortcomings might be mitigated to ensure that future built environments are created and created using truly sustainable concepts as their basis.

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Introduction

The practice of sustainability in the building industry has evolved immensely over the past few years and will continue to do so in the future. Due mainly to an increased awareness of climate change, and with the intention of reducing carbon emissions associated with buildings, a variety of green building rating systems have been developed around the world to address different aspects of buildings such as energy efficiency, water consumption, materials, indoor environment and occupant comfort. Many of these rating systems have been supported and adopted by government entities that require all new developments to achieve their requirements. Similarly, private developers demand that their buildings be designed in accordance with these rating systems, seemingly doing their part in fighting climate change.

When looking at the bigger picture however, it is evident that these new codes and rating systems have had somewhat limited success in changing the fundamental unsustainable aspects of built environments. One such aspect is architecture, the common perception of which is still the generation of new forms for buildings. This is facilitated by continuous advancements in computer-aided design (CAD) technology that enable the creation of unprecedented geometries, as well as other building technologies that have the ability to make such buildings both constructible and habitable. In his book *The Shape of Green*, Lance Hosey argues that beauty and sustainability do not have to oppose each other, yet the perception and reality is that they often do [1].

Integrative design or 'beauty comes first'?

Most green rating systems call for an 'integrative design approach' but have arguably not created the significant transformational shift necessary to change the way in which buildings are designed to meet sustainability challenges. Despite changes in style, architecture has continued its preoccupation with new ways of expressing the prestige of the owner, which is especially the case with developments labeled as 'iconic'. The shape of the building is often decided by a design competition in which architects submit designs judged purely on the basis of visual impact. The geometry of the building is justified in visual terms, continuing the status quo of an architect determining the form and an engineer making it work. This goes against what integrative design is supposed to be. Sustainability is being treated as an 'add-on' rather than an integral part of the design process. In some cases, aspects of sustainability have created building forms that are said to be derived from the sun, the wind, or other natural phenomena – but rarely is there an explanation as to how these particular forms, as compared to others,

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have helped to create buildings that are more efficient and environmentally responsive.

In his July 2012 article in *The Architectural Review*, Peter Buchanan provides some insight into how two different design approaches address structure, occupant comfort, embedded carbon, and – ultimately – what the design takes as its priority. He compares these approaches using Zaha Hadid Architects' London Aquatics Centre and Hopkins Architects' Velodrome – both designed for the 2012 London Olympics. The London Aquatics Centre's shape was said to be inspired by the dive of a swimmer and had its geometrical parameters 'frozen' at competition stage, halting any further refinement. The Velodrome, on the contrary, was the result of a multi-disciplinary design approach that integrated functional, structural, and environmental aspects of the building and had a final form that was the result of an iterative process of optimisation. From competition stage to final form, the design team succeeded in eliminating 35,000 m^3 of internal volume from the building, thus reducing the amount of air that needed to be conditioned [2]. Through the early appointment of the contractor, ISG, the solution for the roof structure was changed to a cable net system following the contractor questioning the choice of the structural steel system preferred by the Olympic Delivery Authority [3]. This meant that the Velodrome's structural system had to be redesigned but proved to be a good decision as it reduced the amount of steel by 27% and cut 3 months from the construction programme [4]. The difference in the outcome of each design approach shows most for embedded carbon. Both buildings have roughly the same roof area, but the Aquatics Centre has 3000 tons of structural steel and the Velodrome has only 1000 tons. This is equivalent to an embedded carbon level of 2.80 tCO_2/m^2 of roof area for the Aquatics Centre compared to an impressively low 0.56 tCO_2/m^2 for the Velodrome [5].

The shortfall of energy simulations

In Apple Inc's 2015 Environmental Responsibility Report, the Apple Campus 2 is claimed to consume 30% less energy than a typical research and development (R&D) office building [6]. The use of the term 'typical' here is misleading however, as no explanation is given for what 'typical' means or the methodology used to define the term in this context. Knowing that the building is targeting a LEED rating, the standard ASHRAE 90.1 Appendix G will be used as a reference and ASHRAE's baseline as the typical building being referred to. However, that baseline does not accurately represent the energy parameters of a typical building. For instance, the exterior envelope U-values used for the baseline are determined by ASHRAE on the basis of where the building is located. In this case, Apple Campus 2 is assigned to Climate Zone 3B and its exterior glazing has a U-value of 3.69 W/m^2 K – almost double the current industry norm of 1.90 W/m^2 K. This difference is more apparent in hot climates (Climate Zones 1A & 1B) where that baseline value is set at 6.81 W/m^2 K – three and a half times the norm. But a greater flaw with ASHRAE is the way it generates the architecture of the baseline model to which the proposed design is compared. The baseline model is stripped of any shading geometry that the proposed building might have, and its glazing ratio is limited to 40% (but only if the proposed design exceeds that ratio) [7]. This is ineffective given the ultra-high thermal transmittance assigned to the exterior glazing of the baseline to begin with. Other than these two parameters, the architecture of the baseline is identical to the proposed. Whether the building is shaped as a swimmer's dive, an egg, or a doughnut in this case, the baseline would still have the same geometry as the proposed. This means that if a building, as a result of the architect's vision, has an inherently flawed geometry – that of a starfish, for example – it would be compared architecturally to that very same configuration under ASHRAE 90.1 only with unrealistically bad glass. This is allowing projects to claim large savings by implementing only marginal design enhancements.

Despite all the good they do, green building rating systems can be used to project an image of sustainability for quite inefficient buildings, and give both architects and clients evidence to justify a design. As with the case of the Bank of America building in New York that recently received a prestigious LEED Platinum rating, it does not matter if the development consumes more energy than many other non-LEED buildings[1] or if it had a 75% window-to-wall ratio [8,9]. As long as it receives the rating then the architects and client can say they have done their part in fighting climate change, and this strategy will be applied by other less well-known architects and clients as well. The negative effect this is having on the aspirations to cut carbon emissions is evident in the fact that, on a global level, the total energy consumption in the buildings sector grew by 1.8% per year between 1971 and 2010 [10].

The cost of architectural beauty

When prominent architects were working on their visions for architecture in the twentieth century, they had little concern about how these visions – when transformed into actual buildings – would affect occupant comfort and the environmental performance of the built environment. Evidence from the architectural literature of that era to support this assertion is found in Le Corbusier's proposal of having one building for all climates.[2]. Another example is Mies van der Rohe's design for the Friedrichstrasse in

Berlin in 1921, which featured the first fully single-glazed building and which was not realised due to air-conditioning systems not being sufficiently advanced to make it habitable [11]. Later advancements in air-conditioning and illumination technology – particularly in the 1950s and 1960s – enabled similar buildings to be designed and built with little or no regard to their climate or orientation and yet still be habitable.

In the post-WWII era, rectilinear-shaped buildings with full single-glazed façades were a common typology. These buildings were preferred by big corporations and clients as they projected prestige, confidence, and prosperity to the public and were a sign of a progressive city. They typically had a window-to-wall ratio (WWR) between 50% and 75%, and a façade U-value between 3.3 $W/m^2.K$ and 4.2 $W/m^2.K$, compared to a WWR of 20% to 30% and a façade U-value of around 2.6 $W/m^2.K$ for the former generation of buildings from 1916 to 1951 [9, Table 4]. One would expect that with such large glass façades these buildings would have almost no need for artificial lighting inside their spaces, but the opposite is true; many of these buildings had dark tinted glazing (usually bronze or grey) for aesthetic reasons and had a low visible light transmittance value when compared to clear glass. This meant that little light was actually penetrating into the building, an effect further worsened by deep open office floor plans, and this resulted in an increased demand for artificial lighting [9]. Unsurprisingly, buildings constructed between 1965 and 1969 had an energy consumption that was more than double that of those constructed between 1950 and 1954 [9, Figure 5]. With low oil prices (and thus energy prices) during that era, the running costs of these buildings could be afforded by clients and no foreseeable end could be seen.

This architectural short-sightedness was brought to an end by the first oil crisis of 1973. Clients could no longer afford single-glazed buildings with nearly 80% glass façades and research into ways to reduce the amount of energy consumed by buildings began. This led to the majority of buildings constructed after the oil crisis having significantly lower façade U-values of around 1.0 $W/m^2.K$ to 1.5 $W/m^2.K$ [9, Table 4], and a relatively lower window-to-wall ratio. Preference was also given to clear glass as opposed to bronze or grey and, as a result, the demand for artificial lighting was reduced. A good example of how the oil crisis affected the design of buildings can be seen from the design of Tour Fiat and Tour Elf by architects Roger Saubot and François Jullien in La Défense, Paris. Tour Fiat, designed in 1972, featured black granite on its façade along with dark-tinted windows. It had deep open-plan office floors which, with the added effect of dark tinted windows, allowed little daylight penetration into the building's core areas [9, p. 600]. Tour Elf, intended as a twin tower for Tour Fiat, had to be redesigned following the 1970s oil crisis and complaints from Tour Fiat's occupants [13]. With both towers having roughly the same amount of office space, the Tour Elf was broken into several volumes to reduce the depth of the floor plan and provide all occupants with better levels of daylight. This was further enhanced by glazing panels with suitable light transmittance yet which were well insulated due to recent advancements in glazing technology. These enhancements, coupled with an advanced building management system, resulted in the heating, illumination, and maintenance cost of Tour Elf being half that of Tour Fiat [9].

This shows that technological advancements do not always translate into reduced total energy usage and can sometimes contribute to a less efficient design. Had there been no advancements in building lighting and air-conditioning systems, fully-glazed buildings would have remained similar to the Friedrichstrasse in Berlin – uninhabitable and never realised. Similarly, advances in glazing technology, stimulated by the oil crisis, resulted in the glazing ratios rising again at the end of the twentieth century – alongside a fall in oil prices – thereby lessening the energy benefits of such advancements. This trend is evident in almost all energy sectors. Between 1972 and 2002, the efficiency of home appliances increased immensely but the amount of electricity consumed by these appliances in the UK has doubled [14]. When it occurs in the buildings sector, this phenomenon is described as the architectural rebound effect,[3] whereby advances in materials technology, construction methods, and even CAD (by way of generating new extravagant forms and constructing them) can sometimes lead to an increased consumption through inefficient designs that, essentially, were only made possible by those very advancements. Given such a history, the recent collapse in oil prices in 2015 means that it should not be a surprise if less actual concern for energy-efficient building designs is seen in the near future.

The purpose of architecture

Architecture began by providing people with a safe shelter in which to live. It progressed from protecting people living in harsh conditions to creating comfortable indoor environments using the technology and resources available at the time. The people of Persia used wind catchers or *badgirs* as early as 4000 BC to channel incoming breezes and exhaust stale air [15]. The principle of the wind tower is based on positioning it to face incoming winds. Air then enters the tower and is distributed inside the house, leaving as it gains heat from the interior. Some wind towers featured a wet deck beneath them in order to promote evaporative cooling [16]. Persians also devised an ingenious solution for storing ice during the hot arid summer months. As Hosseini and Namazian explain in their paper, ice pits or *yakhchals* were used in numerous locations inside Iran where ice was produced during the winter months for use during the warmer summer months [18]. These ice pits consisted of two main parts: an ice cavity of rectangular shape with a depth of around 40 to 50 cm, and an ice storage reservoir. The cavity was usually surrounded by high walls on three sides to shade it from the sun coming from the south, east and west. Water would be poured into these cavities and left to freeze overnight then collected the next morning and stored in the ice reservoir. The reservoir had a vaulted shape with a diameter of 13 m and a height that could reach 15 m, with a vent at the top for hot air to exit through. It extended below ground approximately 6 m, where the ice would be stored, benefiting from the earth's seasonal delay effect and thus maintaining its 'coolth' throughout the summer season. At the bottom of the vault was a well that facilitated the infiltration of melted water to prevent it from melting the ice surrounding it. This architectural solution enabled Persians to enjoy cold beverages and ice cream, as well as store their meat and vegetables and keep them fresh during the hot summer months through natural means.

It is unfortunate to see architects ignoring such passive design techniques in favour of modern refrigeration technology that frees them from climatic constraints and allows them more flexibility in their designs. As Banham explains in his book, environmental considerations are completely passed on to the engineers, and architects do not need to account for them any more [19]. Architecture's focus has been diverted to the generation of artistic forms rather than the solving of critical problems. What further worsens the case is that green building codes often assume mechanical cooling and ventilation systems as a baseline, and the necessary comparative energy savings can be achieved with no consideration of passive techniques, consequently discouraging project teams from exploring such options.

One modern exception is the Eastgate Building in Harare, Zimbabwe, designed by architect Mick Pearce and Arup. The design is said to be based on a combination of two understandings of how termite mounds function. The first, proposed by Martin Luscher, claims that the heat generated by the termites produces sufficient buoyancy to drive the nest air up into the mound's porous surface, where it is refreshed as a result of heat and respiratory gas exchange with the atmosphere. Fresh air, being denser, flows down into the nest and the cycle is repeated.[4] The second model is commonly known as induced flow or the stack effect. With this, the large chimney vent is exposed to higher wind speeds, causing a Venturi effect that draws fresh air into the nest through ground openings. The Eastgate Building cleverly implements a combination of these ideas by utilising low-capacity fans on the first floor of the building to draw fresh air into the floor void. During the night-time, cool fresh air exchanges heat with the carefully-designed 'toothed' concrete slab, storing 'coolth' in the slab due to its high specific heat capacity, which is later used to cool the building. This cycle is further enhanced by occupant activity, which heats the fresh air that rises to the ceiling exhaust shafts and finally exits the building through the chimney [21]. This intelligent design decreased the construction cost by US$3.5 million and resulted in ongoing annual operational cost savings [22]. The importance of finding passive solutions that offer comfortable indoor environments is vital in these modern times when the energy consumption of space heating, water heating and space cooling accounts for nearly 55% of global building energy use, especially given that the energy consumption of space cooling in buildings increased by 60% between 2000 and 2010 [10]. Whilst advancements in mechanical heating, ventilation, and air conditioning (HVAC) systems have ensured comfortable thermal conditions inside the built environment, a holistic approach to sustainability in the buildings sector is not realised without the integration of passive design measures into the design at an early stage, wherein cooling and heating are provided by active and passive means through a hybrid system, thereby immensely reducing the energy load.

Conclusion and recommendations

Buildings account for 40% of global energy use and 33% of global greenhouse gas (GHG) emissions [23]. Reducing the energy use associated with buildings is therefore a critical element in the efforts to combat global warming and climate change. Developed and developing countries have both introduced sustainability initiatives into the buildings sector as an attempt to reduce building energy consumption and, ultimately, reduce the GHG emissions associated with it. These initiatives have succeeded in shifting the market towards more sustainable practices, but they have had little success in reducing the total energy consumption and GHG emissions. Part of the problem lies in the architecture that is expected to deliver new and extravagant forms despite claims of being shaped in accordance with environmental criteria. These claims are further supported by the use of the latest computing technologies which show these buildings achieving remarkable savings over 'typical' ones, even though typical is in this case an ill-defined term. Green building regulations and rating systems have done very little to change this, and consequently unreasonably large buildings with quite unsustainable features continue to nevertheless achieve impressively high 'green' ratings. When this approach is implemented by famous architects and marketed by architectural media as sustainable and beneficial to the planet, it encourages others to follow the same path and compound these negative effects.

A thorough rethink of the concept of architecture is needed in order to assess how buildings can be designed to ensure that the needed carbon emission reductions are met in the future. Further research also needs to be conducted into green building regulations and codes to evaluate why their requirements are not translating into significant total energy savings and how they can be improved to do so. The integration of passive and active design measures to provide comfortable thermal conditions must be studied in order to reduce the burden on mechanical HVAC systems. Finally, policies must be put in place on the higher level to mitigate the rebound effect and ensure that improvements in energy efficiency and building technology do not result in increased absolute energy consumption.

Notes

1. The Bank of America building has an Energy Star score of 50, representing average energy performance [8].
2. In his book *Précisions* (1930), Le Corbusier states: 'Every nation builds houses for its own climate. At this time of international interpenetration of scientific techniques, I propose: one single building for all nations and climates, the house with respiration exacte […] I make air at 18 °C and at humidity related to the state of the weather. A fan blows this air through judiciously disposed ducts, and diffusers have been created to prevent droughts' [12].
3. The rebound effect (or take-back effect) is a term used to describe the extent of energy savings gained through efficiency increases that is taken back by consumers through higher consumption in the form of either longer periods of use or a higher quality of energy service [17].
4. However, recent research by Turner and Soar [19] has revealed that the nest's temperature closely follows that of the soil, and that there is no evidence to suggest that air is being driven out of the nest. This led both researchers to propose that the whole system acts rather like the human respiratory system, with the termites acting as mobile alveoli, finer tunnels within the mound as the bronchioles, and the chimney at the top as the trachea [20, 21].

Disclosure statement

No potential conflict of interest was reported by the author.

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