Sustainable building and construction services in developing countries: the challenge to find “best-fit” technologies

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Summary
Intelligent energy efficiency technologies in developing countries can be assessed on the basis of best-fit criteria (usable controls for occupants, minimum conflicts in operation, inherently energy efficient, and easy to build, maintain and operate). This article argues that ostensibly energy efficient solutions will not perform as intended unless they are appropriate for the climate, are well detailed, installed and commissioned, and are of a level of complexity that can be understood by managers and users of the building. Relevant low-energy technologies include greywater recycling systems, passive and active thermal storage, and ground-source heat pumps. Successful export of such technologies on a wide scale will depend on developed countries setting an example at home. For low-energy building design to have a lasting momentum, commercial clients and governments on both sides of the economic divide need buildings that broadcast a commitment to proven – rather than theoretical – energy efficiency.

Résumé
Les technologies intelligentes d’efficacité énergétique des pays en développement peuvent être évaluées à partir de critères dits les plus adéquats (boutons de réglage utilisables par les occupants, minimum de difficultés dans l’utilisation, efficacité énergétique intrinsèque, facilité de construction, d’entretien et d’exploitation). L’article soutient que les solutions à haute efficacité énergétique ne donneront pas les résultats attendus si elles ne sont pas adaptées au climat, correctement expliquées, installées et mises en service, et si leur niveau de complexité n’est pas à la portée des gestionnaires et des usagers du bâtiment. L’auteur analyse les technologies à bas profil énergétique, notamment les systèmes de recyclage des eaux grises (eaux usées traitées), le stockage thermique passif et actif et les pompes à chaleur géothermiques. L’exportation à grande échelle de ces technologies dépend de la capacité des pays développés de montrer l’exemple chez eux. Pour que les projets de construction à bas profil énergétique se généralisent de façon durable, les maîtres d’ouvrage et les gouvernements des deux côtés de la fracture économique ont besoin de bâtiments qui témoignent d’une recherche d’efficacité énergétique réelle, plutôt que théorique.

Resumen
Las tecnologías inteligentes de eficiencia energética en los países en desarrollo se pueden evaluar a partir de bases de criterios de “mejor concordancia” (controles prácticos para ocupantes, conflictos mínimos en el funcionamiento, eficiencia energética inherente, fácil de construir, mantener y manejar). El artículo plantea que soluciones que son eficientes claramente en materia de energía no producirán los resultados esperados a menos que sean apropiadas para el clima, que se hayan detallado, instalado y encargado correctamente y cuyo nivel de complejidad pueda ser comprendido por los administradores y utilizadores del edificio. Se analizan tecnologías relevantes de bajo consumo energético, por ejemplo, sistemas de reciclaje de aguas grises, almacenamiento termal activo y pasivo y bombas de calor geotérmicas. El éxito de la exportación a gran escala de estas tecnologías dependerá del buen ejemplo que den los países desarrollados en casa. Para que el diseño de la construcción de bajo consumo energético tenga un impulso perecedero, los clientes comerciales y los gobiernos de ambos lados de la línea divisoria económica necesitan edificios que propaguen un compromiso a la eficiencia energética comprobada en vez de teórica.

Greenhouse gas emissions do not respect national frontiers. Developed nations export their technology and skills, and in turn the developing nations are highly depraved of the functionality of construction that the West can offer. With international carbon trading becoming a very real prospect, the onus is on nations with the design knowledge, products and installation skills to ensure that buildings in the developing world also benefit from robust, energy efficient solutions.

In the UK, buildings of all kinds account for around 50% of total greenhouse gas emissions. Much of these emissions is generated by consumption of gas and electricity for space heating, refrigeration, mechanical ventilation and humidification systems, along with electric lighting, catering equipment, and what are known as small power loads, such as computers and general office equipment. The onus is clearly on those who design and construct buildings (and those who operate them) to ensure that the normal state for all this equipment is one that is inherently energy efficient.

The problem is, there are few examples where a technological advance, often intended to improve quality of life, has not led directly or indirectly to an increase in energy consumption. Indeed, some innovations intended to reduce energy consumption have had the opposite effect. Therein lies a threat: where developed countries lead, developing countries are sure to follow.

Technology in itself, then, is not a solution. Neither is it wise to tot up the theoretical savings in carbon emissions from the application of ostensibly energy efficient technologies – be they photovoltaics, greywater recycling plant, natural ventilation devices or low energy lamps – and believe that net savings will automatically result. Often the reverse is true, with the technology not performing due to shortcomings in design, commissioning or management, or simply because of extended hours of operation. Some energy saving technologies are simply switched off because they are too complex for building owners to manage.

Such “revenge effects” of so-called smart technologies are rife. Even buildings in the UK lauded for their intelligence or their low energy attributes have subsequently proved to consume more fossil fuel than their designers intended.

If developed countries are to invest in providing low energy infrastructures for the developing world, we need to know what techniques and technologies are appropriate for each context. We also need to be sure that the intrinsic complexity of solutions will be well within the capabilities of the people subsequently responsible for their operation and maintenance. Such solutions can be called “best-fit” technologies.

Best-fit technologies
A best-fit technology can be defined as a solution that is appropriate for a particular context. Technical solutions need to be assessed for their functionality for the user, for reliability in operation, for buildability (given local skills and resources) and for manageable complexity. As with any technology,
Sustainable building and construction

from a brick to a computerized building management system, the commodity must be available and obviously must be suitable for the climate.

Any product or solution that passes these tests could be defined as intelligent, if only on the basis that wisdom has been applied to the selection and management criteria.

Building intelligence certainly has little to do with complexity, with electronics or with automation. A technically smart item of kit used in the wrong context will probably default to stupid modes of operation. If a technically complex solution is specified on the basis that it is a fit-and-forget item, but proves to be a fit-and-manage item, then its success is out of the hands of the designer and in the laps of the poor souls running the building.

Research also shows that the best intelligence in buildings resides with the occupants. If so, the challenge for designers and manufacturers is to support them with appropriate and understandable systems which have readily usable control interfaces, and which give immediate feedback on their performance.

Given this range of conditions for best-fit technology – usable controls for occupants, minimum conflicts in operation, inherently energy efficient, and easy to build, maintain and operate – which ones are most applicable for use in developing countries?

Table 1 lists the virtues and drawbacks of various building technologies systems in the context of their application in developing countries. A more detailed review of some of these systems is given below.

**Fabric energy storage**

Given the inherent problems of operating mechanical building services in regions of the world where energy sources may be unreliable, along with the likely lack of engineering skills to maintain those services, it makes sense to adopt passive solutions wherever possible. The most obvious approach is to use the building fabric as a medium for storing, cooling and heating energy. Most continental climates tend towards quite wide diurnal swings in temperature; in Zimbabwe, for example, summertime temperatures can range from 16°C at night to 33°C during the day, which gives considerable scope for using thermal mass to control internal temperatures without recourse to mechanical cooling or heating.

Heavyweight structural elements are the simplest form of thermal storage system, their primary characteristic being their slow thermal response, which enables the structure to be used as a medium for storing cooling and heating energy. Exposure of such structural elements to the occupied spaces serves to control the diurnal swings in environmental temperature and provide more of a steady-state internal environment.

However, most building fabric energy storage systems need control over the heat flows in and out of the building, and over the time and place of release. This requires active energy storage, which in turn may require air flow control devices and quite possibly mechanical fan power.

**Active energy storage**

Active energy storage is where controls are used to regulate the flow of heat energy into and out of a building. This can be anything from penny-flap dampers controlled by occupants to complex mechanical ventilation systems that use air to charge and discharge the structure with heat energy.

A good example of how this can be applied to developing countries is the system designed by consulting engineers Ove Arup and Partners and architect Pearce Partnership for the Harare International School in Zimbabwe. Here, the active energy storage system is based on cages of loose rock that act as thermal batteries.

Situated within the tropics, Harare International School was built in 1998 to meet the schooling needs of expatriate children from over 50 nations. The school block features 12 classrooms and laboratories, an art block, and a central music room with associated stage and amphitheatre. Supply air to the school's classrooms is pumped through steel cages containing locally-sourced granite pitching stone, after which the tempered supply air enters the classrooms through low-level grilles.

During summer nights cool air is blown through the building via the rock stores, which are cooled by the very cold night air that is a feature of the local high veld climate. The ventila-
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**Ground-source heat pumps**

Ground-source heat pumps are another way to generate heating and cooling energy while reducing reliance on sources of primary energy. In effect, heat pumps use the vapour compression cycle to generate heat across a wide temperature range that enables it to be used in either a cooling or heating mode.5

They are two basic types of heat pump: water-to-air and water-to-water units, depending on whether the heat distribution system uses air or water. Ground-source heat pumps take energy stored in the ground, which is stable year-round below a certain depth. The normal increase in the earth’s temperature is between 1.5°C and 4.5°C per 100 metres, or an average energy flow of 60 mW/m².

This heat energy for the pump can be extracted through a closed or open-circuit borehole. Closed loops generally rely on the latent heat of the surrounding rock, into which heat-exchange

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Additional text:
- The sports building benefits from a pair of specially engineered wind-driven extractor. Likewise, the sports building benefits from a pair of periscope-shaped wind cowls that turn in opposition to each other, and in so doing provide passive supply and extract.
- The art block passive ventilation is promoted using a specially engineered wind-driven extractor. Likewise, the sports building benefits from a pair of periscope-shaped wind cowls that turn in opposition to each other, and in so doing provide passive supply and extract.
- The installation successfully met the requirements of intelligent, best-fit technology: easy to source and build, easy to maintain, and reliable in operation. It can also be easily replicated without having to import specialist skills or equipment.

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### Table 1

**Benefits and shortcomings of energy saving technologies for developing countries**

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Whereas disinfection is not necessary for rainwater systems used in toilet flushing, a disinfection system is vital for greywater systems as the proliferation of harmful bacteria can pose a health hazard. Greywater systems require periodic topping up of disinfectant and the cleaning and replacement of filters. Filter maintenance, and this can easily come from a greywater or rainwater system.

The big drawback with open-loop systems is their inability to cope with high heating or cooling loads. Boreholes can be expensive to sink. As several boreholes may be needed to meet a desired output, capital and maintenance costs can be prohibitive. Open-loop systems can also be difficult to maintain. It is not easy to pressureize the ground to accept return water. Users may have to contend with algal growth and the settling out of suspended solids, all of which can block up a borehole.

**Water conservation**

The increasing demand for potable water supplies has put the focus on more efficient use of drinking water, and on ways the wastewater and rainwater can be recovered and used for non-potable purposes such as toilet flushing, site irrigation and makeup water for steam boilers. In countries where drought is an ever-present danger, such systems may be a solution to unreliable water supplies.

Rainwater can be used for drinking purposes once suitable treatment has been applied, such as UV disinfection. The system can be very simple, involving little more than gutters, storage cisterns and suitable pipework. On the downside, the system is dependent on the degree and periodicity of rainfall, and sufficient storage must be provided to sustain the building community, particularly if there is no mains water connection.

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**Conclusions**

Clearly, there are no panaceas when it comes to identifying best-fit building services solutions for developing countries. Some approaches are best left well alone (Table 1), particularly if a proposed system can be fragile in operation. Complex services and controls require excellence in their management, and this may be in short supply in resource-strapped regions of the world.

The myth of building intelligence is that it is fit-and-forget, and that electronic solutions will do the rest. The truth is that many building services systems are fit-and-extend, and problems will always occur where complex technology is applied in a context that is deficient in skilled facilities management. Simpler, more robust solutions are more suitable for these contexts, even if the theoretical energy savings would be less than optimal.
Is it possible that controlled application of best-fit technologies in developing countries will drive reductions in emissions of greenhouse gases? If the design practices typified by the Harare International School can be replicated on a regular basis, then there is every hope that they will. However, it is sobering to note that there is one thing developing nations want, and that is to become developed nations. Evidence suggests that their inspiration often comes not from the best that environmentally sustainable architecture can offer, but from what developed nations themselves clearly prize: ostentatious architectural symbols of wealth and prosperity. That tends to manifest itself through externally mounted building services and 100% glazed facades - facing south.

It matters not whether these buildings are the posthuminous consequence of talented designers making their names by proposing fundamentally flawed designs, and then making them work through technical skill and panache. They are desired symbols of national economic prosperity that do not go unnoticed by emerging economies.

Western design communities need to recognize the risks in what they do at home, and try harder to acquaint themselves with a good knowledge of the properties of materials, embodied energy and sustainability. It is a process with multiple participants, including design professionals, owners, users and responsibility. Another important principle of open building is that users/inhabitants may do so in part because they can adjust with reduced waste and disruption.

Under open building principles, an urban design enables a variety of buildings to be erected and replaced without altering the basic urban patterns of space and infrastructure. A base building with parts shared by all occupants enables freedom of layout at the level of the individual unit; a fixed arrangement of walls and doors enables a certain variety of furniture arrangements. This approach ensures that as buildings and neighbourhoods are constructed and altered, each “social unit” (e.g. city council, condominium association, individual occupant) is assured a clear measure of both freedom and responsibility. Another important principle of open building is that users/inhabitants make design decisions; more generally, design is a process with multiple participants, including various kinds of professionals. Adapted from CIB leaflet on open building (www.decco.nl/obi/obi_flyr.htm)

The open building concept for an adaptable built environment

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The open building (OB) approach facilitates systematization of the built environment as a set of distinctly layered sub-systems. One sub-system can be replaced by various alternatives without disturbing other sub-systems. The exchangeable nature of sub-systems makes it feasible to customize a building according to the stakeholders’ specific requirements, and to adapt to requirements that are constantly changing.

This concept is applicable to the efficient regeneration of existing buildings, as well as to the realization of “upgradeable buildings” and “partnership-based growing buildings”. By continuously improving serviceability and resource productivity, the open building approach improves a building’s sustainability.

A building is a complicated assembly of various elements that embody the complicated relationship among its stakeholders. To be serviceable over time, a building needs to meet (at acceptable levels) the ever-changing, unique requirements of its stakeholders. However, physical complicatedness and socio-economic entanglement can be obstructive factors with respect to customization according to individual stakeholder requirements and adaptation to the ever-changing requirements of the building.

The open building approach can be the solution to problems related to complicatedness and entanglement. It is a method of subdividing the built environment into clearly distinct levels, which are made up of functional or spatial groups of elements (Figure 1). Using the approach applied in the Netherlands, Japan and Finland, these levels may be referred to as “urban tissue”, “support” and “infill”. In the United States they may be referred to as the “base building” and “fit-outs”.

Levels correspond to specific stakeholders. In the case of housing, “infill” corresponds to residents of dwelling units and “support” to owners and leaseholders. Buildings that do not have distinct levels tend to entangle decision making by stakeholders. However, the open building approach enables
Sustainable building and construction

Notes
2. PROBE: Post-occupancy Review of Buildings and their Engineering, 1995-2002 (a research project managed by Roderic Bunn, former editor of Building Services Journal, for the DTI under the Partners in Innovation collaborative research programme).
4. Ibid.
7. Barnard (op.cit.).

autonomous decision making at each level without the entanglement of different interests. For example, where this approach is applied to housing, the residents of dwelling units (i.e. stakeholders of “infill”) can arrange interiors independently if the arrangement does not expand beyond the defined boundaries between “infill” and “support”.

The potential for autonomy and disentanglement increases the economic and technical feasibility of customization according to stakeholders’ unique requirements by:
- inducing various forms of participation in the design process by users, residents and different types of professionals;
- managing the “buy to order” or “make to order” supply chain of each stakeholder at reasonable cost.

Thus the open building approach can promote various arrangements of “fit-outs” within the framework of a “base building”, respecting the identities of the building’s users and residents.

Based on a number of case studies concerned with changes in buildings over time, Stewart Brand has illustrated the concept of “shearing layers of change” regarding components’ different rates of change. These layers are called “site”, “skin”, “structure”, “services”, “space plan” and “stuff”. The “shearing layers of change” concept suggests how distinct subdivision could enhance continual adaptation through replacement of groups of elements. Distinct subdivision into functional or spatial groups of elements with sophisticated interfaces, using the open building approach, is a form of “shearing layers of change” (to use Brand’s term). It allows replacement of a group of elements with another group that performs the same or a more suitable function. The open building approach therefore facilitates efficient adaptation to changing contexts over time, including:
- adjustability to unpredictable changes in a socio-economic context;
- upgradeability in order to profit from future innovation.

The open building approach has the potential to improve buildings’ sustainability in both developed and developing countries.

Potential of OB in developed countries: refurbishment of existing buildings

In most developed countries, quantitative demand for floor space in buildings is limited by the fact that populations are declining or only slowly increasing. However, qualitative demand for built environment is influenced by ongoing economic and social transformations. Considering the magnitude of resource use for construction related activities in developed countries, it is essential to avoid repetition of demolish-and-new-build as a method of adapting to qualitative demand. The open building approach could be an alternative, systematized and efficient method of refurbishment to adapt existing buildings to changing qualitative demand through continual replacement of “infill” or “fit-outs”.

In both western and eastern Europe there are examples of run-down housing estates being regenerated, using an open building approach that combines:
- rehabilitation of “supports” by landlords and of “urban tissue” by local authorities, including improvement of energy efficiency, amenities and capacity for change;
The open building approach has the potential to enhance customizability and continuous adaptation over time in different contexts in both developed and developing countries. This approach facilitates an emphasis on the value of serviceability, which promotes the dematerialization of building related economic activities. The open building approach can improve the sustainability of buildings not only through technological, social and economic disentanglement, but also through dematerialization.

**Potential of OB in developing countries: upgradeable buildings**

Today’s innovative technology could soon be out of date. If buildings are to be serviceable in a period of rapid innovation, they need to be upgradeable. A large number of new buildings are being constructed in developed and developing countries, reflecting economic growth. However, because of pressure to achieve rapid construction at minimum cost, some new buildings embody an entangled combination of elements that could obstruct upgrading of buildings. This means many buildings with poor energy efficiency and considerable environmental impacts that are being constructed in developing countries risk technological deterioration in the future. If the demolish-and-new-build method were used as an alternative to deterioration, or if these buildings continued their poor environmental performance, this could result in a global sustainability crisis due to huge resource and energy use, waste generation and environmental impacts. To mitigate the probable risk, it is essential to introduce the concept of “upgradeable buildings” (based on the open building approach) in developing countries. “Upgradeable buildings” can be used for a longer period by inducing innovation over time. Japan has experienced the problems associated with less-upgradeable buildings in a period of rapid economic growth. There are several challenging examples of construction of upgradeable buildings in Japan (Figures 2 and 3).

**Potential of OB in developing countries: partnership-based growing buildings**

In megacities in developing countries, informal construction activities play a considerable role in providing shelter to meet basic human needs. However, in many megacities the role of the informal sector is underestimated by the formal sector. Eventually, investments by the formal and informal sectors are fragmented despite the limited resources available for investment. To utilize limited resources efficiently, the “partnership-based growing building” concept (based on the open building approach) needs to be introduced in order to supply quality shelter for as many people as possible. Within the framework of a partnership-based growing building (Figure 4) the formal sector focuses investments on the “urban tissue” and “support” level, while the informal sector is responsible for installing “infill” through utilizing self-help activities. Because of the adaptable nature of the open building approach, a partnership-based growing building can replace or add “infill” and some “supports” and “urban tissue” in the future, responding to socio-economic changes and innovation. This approach gives people hope by demonstrating the “growing” of a building through a transparent process.

**Concluding comments: probable dematerialization using the open building approach**

The open building approach has the potential to enhance customization and continuous adaptation over time in different contexts in both developed and developing countries. As this approach is disseminated, buildings’ serviceability increases their economic value. Especially at the “infill” level, it is probable that an infill supplier could be a service rather than a product provider. Based on the open building approach, the author and industrial partners are currently trying to develop and disseminate a new business model in which infill is leased as moveable property (Figure 5). This suggests that the open building approach facilitates an emphasis on the value of serviceability, which promotes the dematerialization of building related economic activities. The open building approach can improve the sustainability of buildings not only through technological, social and economic disentanglement, but also through dematerialization.

**Notes**